



INSTITUTE FOR DEFENSE ANALYSES

## **International Assessment of Unmanned Ground Vehicles**

D. Paul Sellers  
A. James Ramsbotham  
Hal Bertrand  
Nicholas Karvonides

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## **PREFACE**

This work was performed under the “Unmanned Systems, International Technology Assessment” task for Joint Ground Robotics Enterprise, Portfolio Systems Acquisition, Land Warfare and Missions (Office of the Under Secretary of Defense for Acquisition and Technology (ODUSD) (A&T)/PSA, LW&M)). The technical cognizant official for this task is Stephen Swan. The Institute for Defense Analyses (IDA) point of contact (POC) is Mr. Paul Sellers.



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## EXECUTIVE SUMMARY

This report provides a *snapshot* of current international global capabilities and trends in science and technology (S&T) for unmanned robotic ground systems. In this dynamic field, the global landscape has changed dramatically during the last several years, and these changes have affected numerous technology areas. Trying to provide complete and comprehensive coverage of these changes seems impractical. Rather, the examples and analysis presented here are intended to provide a statistically valid picture of the overall global state of play at this point in time.

Several basic forces are driving the advance of unmanned ground systems (UGS):

- A strong technology push from the growing availability of low-cost sensor and microprocessor technologies
- Requirements pull generated by the need for unmanned systems to deal with non-traditional threats from terrorists and other non-traditional adversaries
- Increasing labor costs because of globalization and pressures toward “leveling the playing field” in terms of wages and standard of living
- Changing societal attitudes toward risk and the acceptability of human casualties and loss of life.

Declining component costs and the fact that work can be done at a small scale have made robotics universally popular for research and development (R&D) worldwide. As a result, nearly every country except the most impoverished will have some activity in ground robotics.

The level of investment in ground robotics for military and homeland security is increasing. The European Defense Agency (EDA) and the Ministries of Defense (MoD) in France, Germany, and the United Kingdom have invested tens of millions of dollars. Recent reports also indicate that Chinese investment in robotics has increased by over 200% since 2002.

The United States, Canada, France, Germany, and Israel have had the most active programs for robotic systems fielded or demonstrated for military use, and several other countries have varying levels of effort in military robots. Those identified to date include

Australia, Belgium, China, Croatia, Finland, Italy, Norway, Poland, South Korea, Singapore, Sweden, Switzerland, and the United Kingdom.

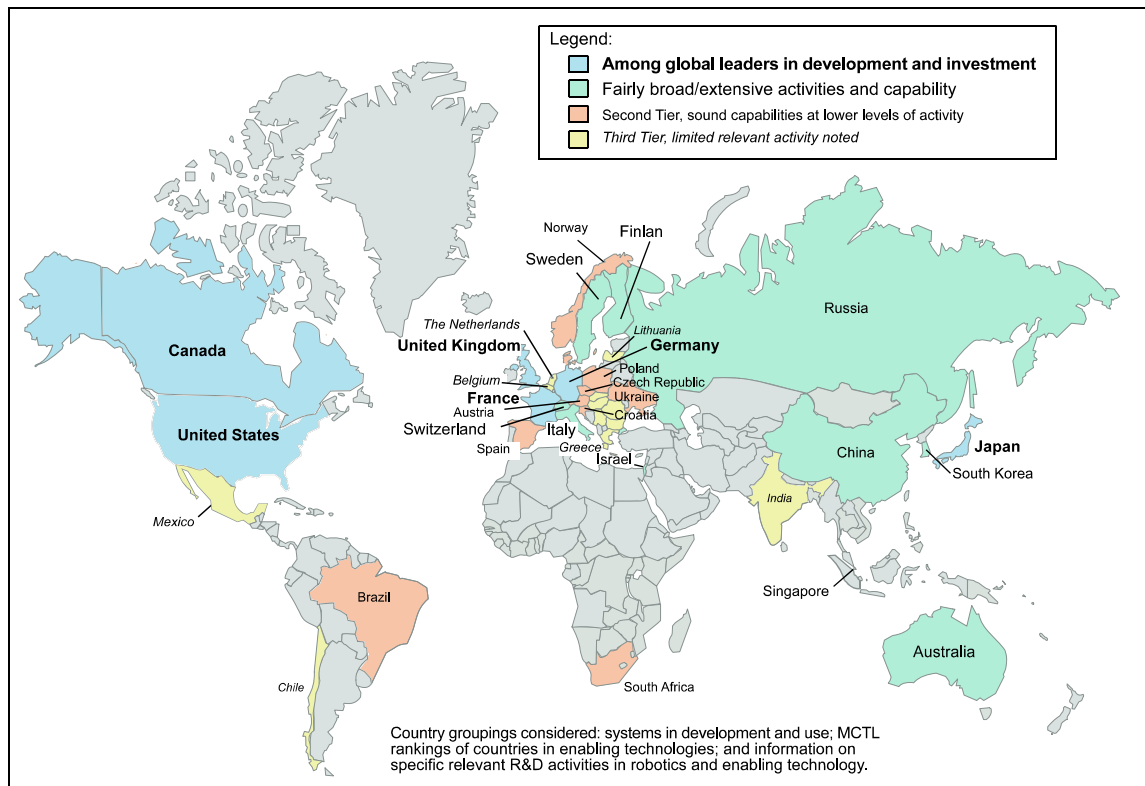
While Japan is a world leader in unmanned ground vehicle (UGV) technologies, it has had little apparent interest in the development of military systems. A likely explanation is that traditional and legal restraints on exports of military systems make investment in such developments economically unattractive. In any case, Japan has the technological wherewithal to conduct cutting-edge work.

While prototypes exhibiting substantial autonomy have been demonstrated, the global state of the art in operational military ground robots is primarily represented by remotely operated or tele-operated systems. Autonomous, unmanned operations, where noted, are generally based on preprogrammed motion or response to simple sensor inputs. Such systems involve limited or no interpretation of on-board sensor data.

UGS and their enabling technologies are quintessentially dual use in nature. However, military requirements may be more stringent than those of their civilian counterparts in terms of the complexity and uncertainty of the operating environments and missions, the pace of operations, and the concern with threat survivability. In most cases, these differences are in degree or level of performance, as opposed to being completely different in kind. While much of the UGS R&D activity is directed toward civil applications, advances in enabling technologies [e.g., sensors; propulsion and traction; autonomous navigation, command and control (C2); human systems interfaces; and multi-agent/robotic systems] will support significant improvements in military systems.

Based on relevant S&T activity in key enabling technologies (e.g., machine vision, autonomous navigation, locomotion, and multi-agent intelligent systems), many more countries now have an active interest in robotics. Figure ES-1 provides an overview of international activity in ground robotics.

The primary missions for existing systems are explosive ordnance disposal (EOD), mine clearing, reconnaissance, load carrying, or security (e.g., perimeter monitoring). Some of these robots are described as “autonomous.” Some use on-board sensors for autonomous navigation and control. However, the operating area is typically well defined and has fixed features that the vehicle can use to locate and orient itself. These tactical situations and responses are thus well bounded and constrained.



**Figure ES-1. Overview of International Activity in Ground Robotics**

By contrast, battlefield environments are unpredictable. As a result, the Department of Defense (DoD) ground robotics programs have invested substantially in advancing the state of the art in sensor-based autonomous control and navigation. The United States arguably enjoys a technological lead in pursuing the leading-edge state of the art technologies. In contrast to the United States, other countries appear to be pursuing the development of less-sophisticated approaches.

A characterization of Israeli efforts in military ground robots summarizes the situation well. Unlike the ambitious U.S. plan to develop and deploy highly autonomous combat robots as part of the Future Combat Systems (FCS) program, the Israeli approach is less ambitious. It values the contributions of autonomously navigated vehicles for rather limited, mission-specific tasks.<sup>1</sup>

Less-sophisticated technology approaches entail less technical risk and may allow systems to be fielded more quickly. This can provide other countries valuable operational

<sup>1</sup> Defense Update. March 2007. Israeli companies pursue new opportunities with autonomous ground vehicles: Elbit expands range of autonomous ground vehicles. Available: [http://www.defense-update.com/features/du-1-07/elbit\\_UGV.htm](http://www.defense-update.com/features/du-1-07/elbit_UGV.htm) (Accessed January 2008).

data/experience that may allow them to advance the state of the art more rapidly in practice.

Finally, in several areas, research is being done in anticipation of future advances in robotics. These, too, were considered in developing a global overview. Specific examples are

- **Work in humanoid and other biomimetic robotic systems.** The challenges of navigating and controlling vehicles on complex, uneven battlefield terrain are severe. For the current state of the art, wheeled and tracked vehicles offer inherent advantages. However, advances in automated controls made in biomimetics may yield benefits. One example is the development of reconfigurable locomotion schemes, which, in essence, combine features of wheeled and pedal methods. Significant activities in this area were noted in Japan.
- **Machine vision.** Machine vision, including, as an important subset, the use of laser detection and ranging (LADAR) imaging and simultaneous localization and mapping (SLAM), has utility in industrial process control, homeland security, and remote sensing. Leading capabilities exist in Canada, France, Germany, Japan, and the United Kingdom.
- **Human systems interfaces.** Human systems interfaces, including virtual and augmented reality displays, are emerging areas of research that appear to offer promise for non-invasive, brain-actuated control of robots.<sup>2</sup>
- **Work on multi-agent systems.** While the implementing hardware has yet to be developed, several countries are pursuing the development of conceptual architectures and techniques to support multi-robot operations. Because so much of this work can be done through modeling and simulation (M&S), it has become a popular topic for academic research worldwide. Among the more active countries are Japan, France, United Kingdom, Russia, Australia, and the Netherlands. Also, the North Atlantic Treaty Organization (NATO) has a Research Task Group (RTG) on Military Applications for Multi-Robot Systems (IST-058/RTG-024)<sup>3</sup> that follows S&T developments in this area and NATO Standardization Agreement (STANAG) 4586 is responsible for standards for unmanned systems, primarily unmanned aerial vehicles (UAVs).

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<sup>2</sup> Millan, J. 2007. Non-invasive brain-controlled robots. Presentation at the PASCAL Workshop at the IDIAP Research Institute, Martigny, Switzerland (April 16–17). Available: [www.maia-project.org/pascal-workshop/pdf/millan.pdf](http://www.maia-project.org/pascal-workshop/pdf/millan.pdf) (Accessed January 2008).

<sup>3</sup> See [http://www.fgan.de/~natoeuro/index\\_nato.html](http://www.fgan.de/~natoeuro/index_nato.html) (Accessed January 2008).

## I. INTRODUCTION

This report provides a *snapshot* of current international global capabilities and trends in science and technology (S&T) for unmanned robotic ground systems. In this dynamic field, the global landscape has changed dramatically during the last several years.

### A. TECHNICAL FRAMEWORK FOR ANALYSIS

For analysis, an unmanned robotic ground vehicle that encompassed the following functional characteristics was postulated:

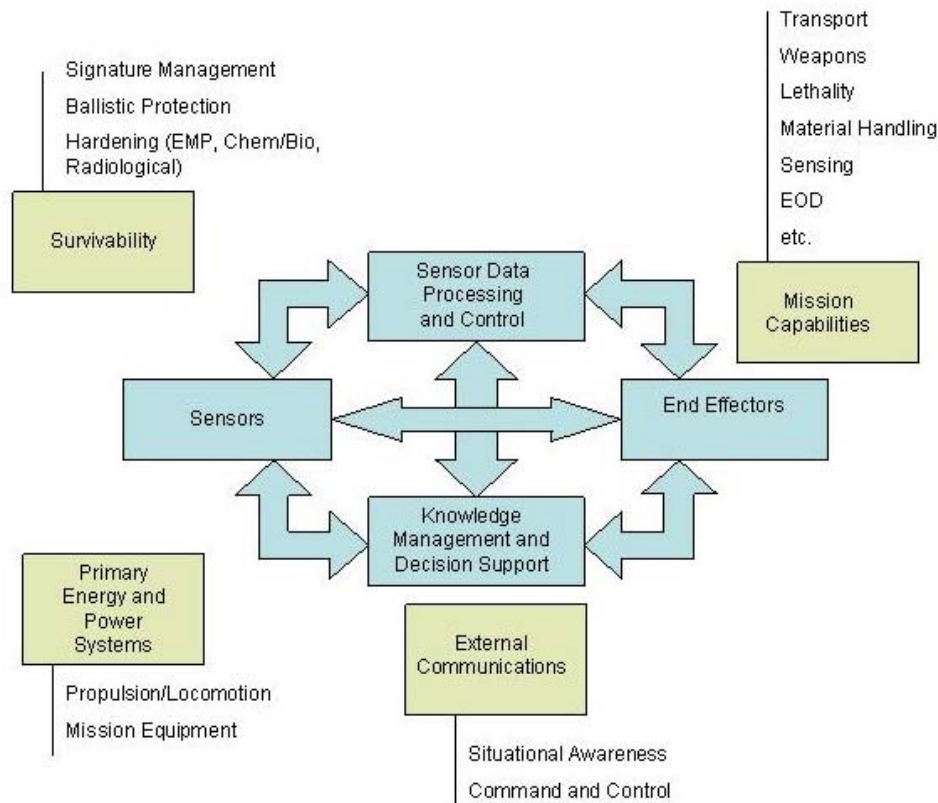
- A sensory and perception subsystem and some level of embedded capability to process and interpret the data
- A control system capable of deciding on courses of action based on sensor data
- An end action that involves mobility (an ability to change location) or at least motility (an ability to move parts of the system to perform functions)
- A system that performs one or more of these functions with some degree of autonomy.

These functions can be implemented in a variety of hardware and software configurations, depending on mission requirements. The myriad ways to implement these functional characteristics require the development of design and documentation standards, such as the Joint Architecture for Unmanned Systems (JAUS),<sup>4</sup> for effective integration and interoperability of ground robotics in a system-of-systems.

Figure I-1 illustrates the wide range of technologies required to meet design requirements of autonomous, unmanned systems that will be capable of dealing with uncertainty in a complex operating environment. A level-of-concept feasibility has been

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<sup>4</sup> JAUS is a Department of Defense (DoD) standard to promote interoperability of unmanned systems and is mandated for use by all the programs in the Joint Ground Robotics Enterprise (JGRE). JAUS is an upper level design for the interfaces within the domain of unmanned ground vehicles (UGV). It is a component based, message-passing architecture that specifies data formats and methods of communication among computing nodes.



**Figure I-1. Key Elements of Ground Robotics Technology**

demonstrated in U.S. prototypes.<sup>5</sup> However, the complete spectrum of operational requirements exceeds the state-of-the-art capabilities in operational ground robotics. Current prototypes include some ability to detect obstacles conforming to predefined specifications, and the most advanced demonstrators have made significant advances in dealing with more realistic conditions. At present, the state of the art is represented by remotely operated or tele-operated systems or preprogrammed systems capable of navigating based on predefined waypoints or environmental features.

This report also addresses work in multi-robot systems. This concept envisions robots interoperating in multiple roles and varying degrees of autonomy with human warfighters and other manned and unmanned tactical systems.

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<sup>5</sup> Army Materiel Command Global Risk Benefit Assessment. March 23, 2006. *Technology security assessment: Military robotics.*

## B. BASIC APPROACH TO GLOBAL ASSESSMENT

Robotic unmanned ground systems (UGS) include a wide range of sizes, types, capabilities, and potential applications. The field and its enabling disciplines are evolving rapidly, and globalization is promoting the rapid spread of the enabling technologies, particularly where mass markets are a potential. Thus, any analysis will, at best, provide a snapshot in time from some limited set of perspectives.

The factors used to assess capabilities and trends:

- Systems already deployed or those in well advanced concept demonstration, which were taken as concrete evidence of capability and investment. However, many systems currently in use were designed decades ago and are, at best, a point of departure for future developments.
- Expert consensus on Worldwide Technology Capabilities (WTCs) in specific enabling technologies, which was based on assessment information from the Militarily Critical Technologies List (MCTL) and interviews with individual experts in the field.<sup>6</sup>
- Specific research, development, and industrial activities from several hundred database records that evaluated specific activities in the United States and abroad. These records, in effect, were a quick-look analysis of data comprising a snapshot of examples of work that represented broader global capabilities and trends.<sup>7, 8</sup>

Countries were assessed using various combinations of these factors. Technical judgment was applied to develop an understanding of the overall state of play and their overall capabilities. Systems in use or in demonstration were given greater weight in the assessment process. For the enabling technologies the MCTL ratings represent a consensus of senior subject matter experts (SMEs). This consensus is subsequently coordinated throughout the Department of Defense (DoD). Records of specific activities from the database were considered as supporting and amplifying data.

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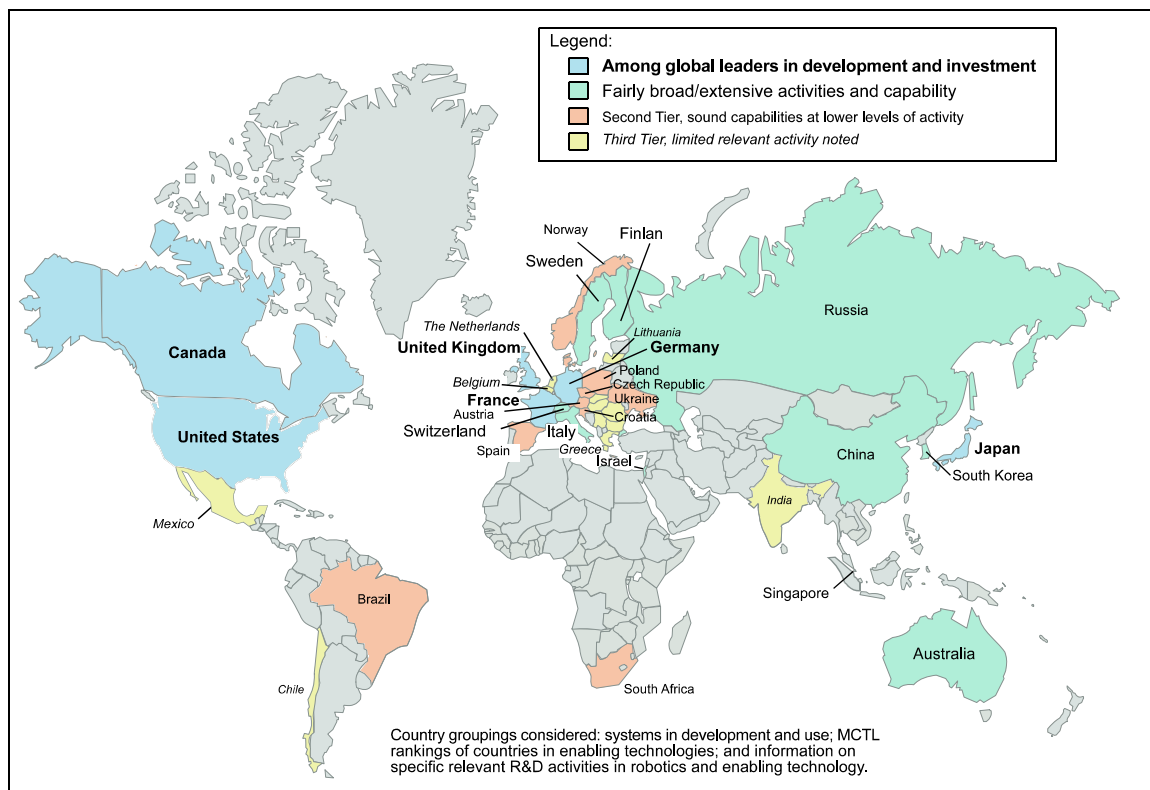
<sup>6</sup> MCTL. June 2007. Section 9.0: *Ground systems technologies*; MCTL. June 2006. Section 10: *Information systems technology*; and MCTL. July 2007. Section 11: *Lasers, optics, and sensors technology*.

<sup>7</sup> Global Technology Knowledge Base (GTKB) [accessible through Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics) (OUSD(AT&L)) Research and Engineering (R&E) Portal], current June 2007.

<sup>8</sup> World Technology Watch® (WTW): Orion Enterprises, Inc (OEI). (The WTW is OEI's proprietary knowledge management system for developing and generating the GTKB and other global assessment deliverables. It is designed to answer three key questions: What is the technology? What is it used for? Who are the leaders and followers in the field?).

Such assessments—and particularly predictive assessments—of rapidly advancing technologies are inherently uncertain. Quantitative scores carry an implied precision that is misleading and inherently obscure key judgments reflected in Section II. The input data are, at best, an approximate *snapshot* because the dynamic nature of this field causes the global landscape to change dramatically and quickly. The resulting assessment of countries is correspondingly a coarse-grained categorization.

Figure I-2 provides a resulting *snapshot* of the global extent of work in ground robotics, taking evidence of such activity into account. Countries identified as worldwide leaders in this area ranked at the top consistently. The countries highlighted in Section III are listed in alphabetical—not ranked—order.



**Figure I-2. Overview of International Activity in Ground Robotics**



## **II. GLOBAL CAPABILITIES AND TRENDS: GENERAL OVERVIEW**

The area of global capabilities and trends produced several general findings. Some 75 operational or relatively mature demonstration systems were identified.<sup>9</sup> The size breakdown uses the categories defined in the Joint Robotics Program Master Plan (JRPMP)<sup>10</sup> as a point of departure.<sup>11</sup>

Given the rate of development and the number of different variants and models of robots entering the market, the 75 systems surveyed cannot be viewed as comprehensive. They are, however, a statistically significant sample of the current and evolving state of the art. Figure II-1 reflects a significant research and development (R&D) trend toward smaller systems. This trend is driven primarily by requirements for man-portable or transportable unmanned systems to support dismounted troops. The increase in the 2,501- to 20,000-lb category appears to indicate a desire for air-transportable systems with greater capability and system battlefield survivability. These systems, in turn, are key to rapid and effective deployment.

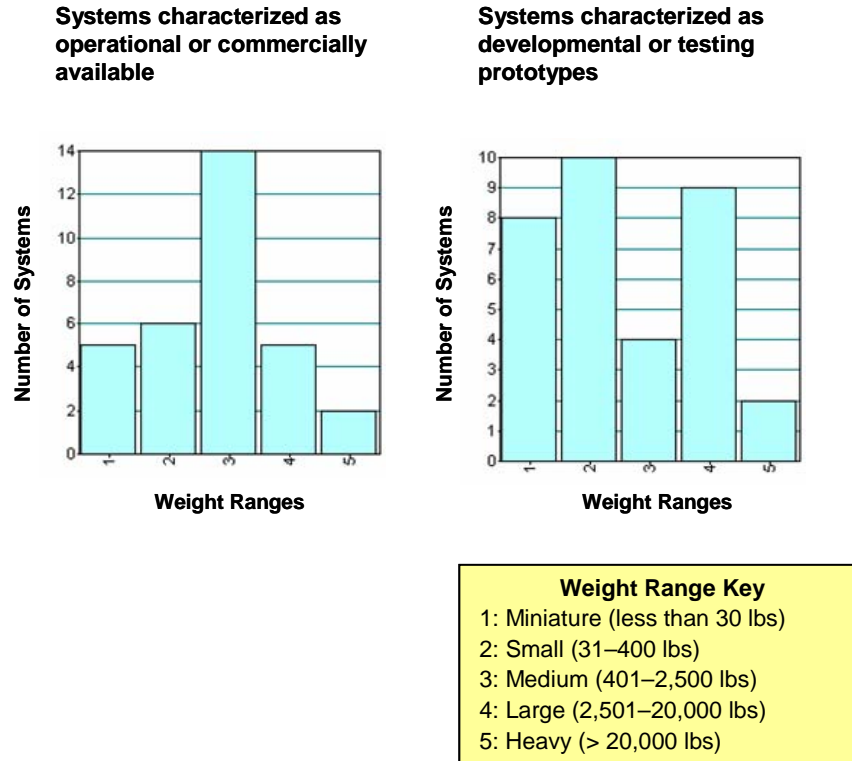
Mission applications represented in the dataset were as follows: 27 explosive ordnance disposal (EOD) or mine clearing; 19 intelligence, surveillance, or reconnaissance (ISR); 10 inspection or security; and 6 load carrying. Only 5 of the 75 systems were designated as having capabilities for combat or engagement. That said, several developers have discussed or presented concepts for weaponization.

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<sup>9</sup> Forecast International. Unmanned vehicles forecast: 3<sup>rd</sup> quarter 2006. Information available: <https://www.forecastinternational.com/fistore/prodtoc.cfm?ProductID=10> (Accessed January 2008).

<sup>10</sup> Joint Robotics Program Master Plan. FY 2005. [The JRPMP is an Office of the Secretary of Defense (OSD) management tool for fulfilling its responsibility to oversee the Joint Robotics Program (JRP). The JRPMP, which is prepared annually and provided to Congress, provides a single, integrated DoD document that lays out the strategies for acquiring first-generation UGVs and for developing technologies critical to follow-on systems. The JRPMP describes the individual projects and the management framework for their execution.]

<sup>11</sup> A category was added for robots weighing less than 31 lbs. Also, the JRPMP does not have a category for systems between 20,000 lbs, which are defined in the JRPMP as small (heavy), and 30,000 lbs, which are defined as large. None of the 70 operational robots identified as operational or in military demonstration programs fall into the 20,000- to 30,000-lb weight range.



**Figure II-1. Key Development Trend: Size Statistics**

Two systems explicitly listed nuclear, biological, and chemical (NBC) defense as mission applications. Systems are typically designed to carry different payloads, and several systems cite more than one mission function. Other applications for the remaining systems are a mix of industrial, entertainment, or not designated.

The most common forms of locomotion cited were wheeled (34), tracked (23), or a combination of wheeled/tracked (5). Technologies for other forms of locomotion noted—bipedal, multi-pedal, serpentine—are less mature. At the moment, the popular notion of humanoid robotic warriors notwithstanding, serious efforts in battlefield robots appear directed toward the use of more mature locomotion technologies.

Of the 75 systems, most (40) were explicitly described as remotely controlled or tele-operated. The remaining systems were described as having some degree of autonomous capability. However, all the systems described as having autonomous capability appear to involve preprogrammed or map-based navigation within a defined operating area. Common uses were perimeter control and security. Systems capable of using on-board sensor navigation and control are still in early development. Further, none of the systems noted appear to be attempting anything as ambitious as the Army's Demo III+

program. Specifically, sensor-based operations appear to be constrained to a much more limited set of conditions.

In summary, in terms of the global state of the art, the reality of autonomous robotics for battlefield use trails popular perception. A fully autonomous, on-board sensor, perception-based operation [navigation and control without the use of preprogrammed map information, a Global Positioning System (GPS), or other cooperative navigations aids] is substantially beyond current capability.

This lack of capability, however, does not translate into non-action. The United States, France, Germany, and Japan appear to be placing greater emphasis on sensor, perception-based autonomy than other countries, and Canada, Israel, and the United Kingdom round out a list of countries that have extensive capabilities to advance the leading edge of the art. In addition, several other foreign efforts could contribute to advancing practical knowledge of UGS. Countries falling into this last category are, in rough rank order, Australia, South Korea, Switzerland, Sweden, Italy, China, Russia, Singapore, and Finland.

Industry trade shows and interviews with industry and foreign SMEs have also confirmed this assessment.<sup>12, 13</sup> Knowledgeable industry experts observe that the United States generally leads in the research areas but that a select group of foreign countries (primarily Israel, Australia, Sweden, and possibly South Korea) are doing significant work in integrating existing unmanned ground vehicle (UGV) technologies and commercial off-the-shelf (COTS) equipment for current and near-term infantry operations.

The countries discussed thus far represent less than half of the countries for which some relevant activity was identified. R&D, particularly in more mature robot technologies and in theoretical analysis of multi-robot systems, is ubiquitous, particularly in academic research. At the same time, the work reported in the popular press often paint an inflated picture of near-term capabilities—particularly for autonomous operations.

An example is RoboCup, an international competition whose stated goal is to “develop a team of fully autonomous humanoid robots that can win against the human world soccer champion team.”<sup>14</sup> Such competitions arguably contribute to advancing the

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<sup>12</sup> Karvonides, N., IDA. Personal interviews with i-Robot SMEs. September 2007.

<sup>13</sup> Karvonides, N., IDA. Personal interviews with EDA SMEs. September/October 2007.

<sup>14</sup> See <http://www.robocup.org/> (Accessed January 2008).

“bleeding edge” of the art. They also elicit visions of robots capable of at least approximating something that looks like competitive soccer. However, at present, the terms and conditions of the competitions are severely constrained. Colors and dimensions of the field and all robot-visible features are precisely defined. “Players” may be limited to specific makes and models of robots. The rules of play are similarly defined and constrained. While the state of play evolves unpredictably, the rules and playing field are static and defined. Finally, even if the goal of defeating a human championship team by 2050 is realized, the conditions of play will not begin to replicate what robotic systems will encounter on the battlefield.

While the challenges are daunting, significant strides are being made in enabling technologies, particularly in sensing and perception. For vision systems for the most advanced autonomous military ground systems, the Army’s LADAR V sensor represents the leading edge of the art. Laser radar and laser profiling also have numerous civil applications. A strong market exists for precise, high spatial resolution (1.0 m to 0.3 m) digital terrain elevation data (DTED) products, which exploit the availability of new, low-cost airborne laser detection and ranging (LADAR) imaging products. Research of this sort will contribute to a growing base of knowledge about target and clutter characteristics that may support the rapid development of sophisticated sensory perception for ground robots.

Thus, research in machine vision is ubiquitous. The European Strategic Program on Research in Information Technology (ESPRIT) program sponsored extensive research in image analysis under the first four European Framework Programmes, and machine vision and image analysis have remained areas of continuing emphasis. Current efforts are part of the Information and Communications Technology Program. Pockets of excellence comparable in quality to those in the United States exist in many other countries. U.S. efforts may be advancing the leading edge of the art, but many other countries are well equipped to exploit such advances.

### **III. HIGHLIGHTED CAPABILITIES**

As noted previously, technologies for unmanned systems are developing and spreading globally at exponential rates. The following discussion does not attempt comprehensive coverage but, rather, is intended to provide readers an appreciation of the current state of the art and key trends.

The following discussion includes multi-national groups and countries that have made the military use of robotics a national priority or were identified as having substantial programs or exceptional infrastructure capabilities. For simplicity, European Union (EU) and North Atlantic Treaty Organization (NATO) activities are addressed collectively. The multi-national activities of other countries follow.

Based on demonstrated capabilities and levels of investment, an attempt has been made to differentiate between countries and groups that appear best positioned to make rapid advances in unmanned military ground robotics and countries that have less capability. However, two caveats apply:

1. The distinction between less capable “world leaders” and more capable countries is based on qualitative judgments and may be small
2. Countries that are ranked lower based on overall capability may, in fact, have unique capabilities in specific niche areas.

#### **A. WORLD-LEADING CAPABILITIES**

##### **1. Activities of the EU and NATO**

The EU and the European Members of NATO have been increasingly active in robotics. Several of these countries rank among the global leaders. In addition, the efforts cited below promote and facilitate the development of an EU Community-wide robotics infrastructure of substantially greater capability.

###### **a. EU Efforts**

The EU has made considerable investments in robotics and enabling technologies for many years, with substantial funding provided on a continuing basis under various

Framework programs since the early 1990s.<sup>15</sup> A significant development for ground robotics was the establishment of the European Defense Agency (EDA) as an agency of the EU. The EDA was established under a Joint Action of the Council of Ministers on 12 July 2004 “to support the Member States and the Council in their effort to improve European defence capabilities in the field of crisis management and to sustain the European Security and Defence Policy as it stands now and develops in the future”.<sup>16</sup>

### **EDA Activities**

The EDA, soon after its establishment, identified an initiative for future Armored Fighting Vehicles (AFV), supported by the development of two feasibility studies: Networked-Enabled AFV and Unmanned Ground Tactical Vehicles. The feasibility study efforts resulted in EDA’s establishment of three new UGV-related R&D programs. EDA launched a fourth UGV-related R&D program for stand-off chemical, biological, radiological, nuclear, and explosive (CBRNE) detection in December 2007. The combined size of these 4 R&D programs totals over \$30M U.S. dollars (USD).

Following is a summary of each program and its known participants.<sup>17</sup>

#### ***Semi-Autonomous Small Ground Vehicle System Demonstrator (SAM-UGV) (or SAM for short)***

This is the EDA’s largest UGV R&D program. The program goals are to

- Identify existing, state-of-the-art UGV (and key subsystem) technology and industrial base capabilities of EDA member countries
- Identify EU UGV military capability gaps (e.g., reconnaissance missions)
- Identify corresponding UGV (and subsystem) R&D development projects, the latter of which will be used to formulate follow-on UGV “integrated development teams.”

End-use applications of the SAM-UGV R&D program are concentrated on future UGV mission capabilities for patrolling, counter-improvised explosive devices (counter-IEDs), and CBRNE detection.

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<sup>15</sup> Most EU research was gathered under the umbrella of the Framework program in 1984, and the structure of the program and its funding has since been approved in 4-year blocks.

<sup>16</sup> EDA Web Page. Background. Available: <http://www.eda.europa.eu/genericitem.aspx?area=Background&id=122> (Accessed January 2008).

<sup>17</sup> Karvonides, N., IDA. Personal interviews with EDA SMEs. September/October 2007.

R&D program participants have not yet cataloged current UGV state-of-the-art technological and industrial-base capabilities that might exist in their respective countries. When completed, findings will identify collective UGV technology capability gaps and define specific EDA UGV R&D follow-on program research projects.

This program is being overseen by EDA member country Germany [the Bundesministerium der Verteidigung (BMVg) (the German Federal Ministry of Defense)]. Country participation includes Germany (Rheinmetall Defence and Diehl BGT Defence), Spain, France (Thales and Canberra Eurisys), Italy (Galileo Avionica), and the United Kingdom (BAE Air Systems).

The program is scheduled to last for 4 years and is budgeted between € 10M and € 12M (up to ~ \$17.5M USD).

#### ***Use Robotics (or “UGV” for short)***

The goal of the second EDA UGV R&D program is to develop a generic “demonstration system” for unmanned vehicle convoy applications (e.g., convoy resupply). The intended platform may be an existing “manned” vehicle(s), and the aim of the R&D program is to develop a UGV “modular conversion kit” for use in various vehicles in the “several tons” class and or upwards (10 to 12 tons). According to the EDA, this UGV should be able to operate in different environments and road conditions and allow the support of a remote operator who can supervise the mission and take control when needed.

Italy’s Ministro della Difesa [Ministry of Defense (MoD)] is overseeing this R&D program. Country participation includes Italy [Consorzio Iveco – Oto Melara (CIO)], Germany (Rheinmetall Defence and Diehl BGT Defence), Greece (Hellenic Aerospace Industry), Spain [Especialidades Eléctricas SA (ESPELSA)], Finland (Patria Group), France (Thales), Poland (Edisoft), Portugal, and possibly Cyprus.

The first phase of this 4-year R&D program is expected to last 9 months and is currently funded between € 1.2M and € 1.4M (up to ~ \$2.07M USD). R&D program funding levels for future phases will not be known until the first phase has been completed. At the end of the first phase, existing state-of-the-art UGV technology and industrial base capabilities, corresponding military UGV capability requirement needs, and associated capability gaps will be identified.

### ***Networked Multi-Robot System***<sup>18</sup>

This program is described as an “open architecture” software tool development (i.e., “test bed”) effort for simulating networked, multi-robot (“collaborating”) systems in ground, air, and sea domains [specifically, command, control, communications, computing and intelligence (C4I)]. Germany’s MoD (BMVg) is overseeing this effort. Country participation includes Germany [Diehl BGT Defence, which leads the industry consortium along with Forschungsgesellschaft für Angewandte Naturwissenschaften e.V. (FGAN) (Research Establishment for Applied Science)], Belgium (Royal Military Academy), Italy (Oto Melara of Finmeccanica), and Spain (Sener Ingenieria y Sistemas SA). This program is a 3-year, € 4.5-M (~ \$6.57-M USD) effort.

### ***Generic Urban Area Robotized Detection for CBRNE Devices (GUARDED)***<sup>19</sup>

This effort includes demonstrating (and presumably developing) a remote-controlled mobile platform for detecting CBRNE devices (materials) with high confidence and at a safe (standoff) distance. Related sensor technologies of interest include ground-penetrating radar (GPR), proton transfer reaction (PTR), and mass spectrometry (MS) for through-wall and buried target detection. This is a 3-year effort budgeted at € 3.5M (~ \$5.1M USD). Country participation includes France (ECA, Orsay and the DDSC, Asnieres-S-Seine), Austria (Ion, Innsbruck),<sup>20</sup> Slovenia (IPS, Ljubljana.) and ENV, Mikeli (Finland.)

GUARDED is one of three new Joint Investment Programs for Force Protection (JIP-FP), a current EDA R&D initiative funded for 3 years at around € 55M (~ \$80.3M USD).<sup>21, 22, 23</sup>

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<sup>18</sup> See [http://www.fgan.de/fkie/site/c179\\_f16\\_en.pdf](http://www.fgan.de/fkie/site/c179_f16_en.pdf) (Accessed January 2008).

<sup>19</sup> See <http://akseli.tekes.fi/opencms/opencms/OhjelmaPortaali/ohjelmat/Turva/fi/system/uutinen.html?id=3571&nav=Uutisia> (Accessed January 2008).

<sup>20</sup> The EDA program information includes reference to Austrian participation by Ion, Innsbruck. This may be a reference to a detector design activity at the University of Innsbruck’s Institute for Ion Physics. However, no other references to this work could be found.

<sup>21</sup> Karvonides, N., IDA. Personal interviews with EDA SMEs. September/October 2007.

<sup>22</sup> EDA News. 14 December 2007. EDA Signs first contracts under R&T Joint Investment Programme on Force Protection. Available: <http://www.eda.europa.eu/newsitem.aspx?id=301> (Accessed: January 2008).



## EU Community R&D Programs

Since the mid 1980s, the EU has sponsored several programs involving mobile robotic technologies that have potential military utility. The projects cover a wide range of topics, with a general objective of promoting the strength and development of the robotics activities in Europe. A few examples of previous and ongoing work in which DoD would have interest include the following:<sup>24</sup>

- **Successful demonstrations of autonomous navigation and control of automobiles operating on European highways.** This work was based on pioneering work done in the 1980s by Ernst Dickmanns at the Universität der Bundeswehr München (Bundeswehr University in Munich) in machine vision and driverless cars. The culmination of this work was two demonstrations. The first was in 1994 near Paris, during which two vehicles operated autonomously at speeds up to 130 km. The second was a 1758-km trip in 1995, during which the vehicle speed at times exceeded 175 km/hr. Although these results were impressive, some important caveats must be noted. First, the vehicles were designed to operate in a well-defined and structured environment, in which human intervention required to deal with unprogrammed conditions. Second, the vehicles did not deal well with impediments such as standing water, where the simple sensors could not readily determine depth.<sup>25</sup>
- **Climbing and walking robots (CLAWAR).** This is an ongoing 3-year effort funded at a level of € 1.23M under the Fifth Framework Programme (FP5).<sup>26</sup>
- **Navigation of Autonomous Robots via Active Environmental Perception (NARVAL).** The long-term objective of this project was to design a controller for an autonomous robot moving in a three-dimensional (3-D) environment and subject to external disturbances and noisy sensory data. The

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<sup>23</sup> Defense Technology International. December 2007. Automation Army: UGVs meet a growing range of battlefield needs. Available:  
<http://www.nxtbook.com/nxtbooks/aw/dti1207/index.php?startpage=28&PHPSESSID=2315d6f3ae931ee6cd2a35b37c60cc31&ncd=content> (Accessed January 2008).

<sup>24</sup> Community Research and Development Information Service (CORDIS):  
<http://cordis.europa.eu/en/home.html> (Accessed January 2008).

<sup>25</sup> Wikipedia Article. Ernst Dickmanns. Available:  
[http://en.wikipedia.org/wiki/Ernst\\_Dickmanns](http://en.wikipedia.org/wiki/Ernst_Dickmanns) (Accessed January 2008).

<sup>26</sup> Community Research and Development Information Service (CORDIS). Available:  
[http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ\\_RCIN=2902865&CFID=4841517&CFTOKEN=36607749&jsessionid=4230a23a610a1d502b1b&q=D8ADA706294D946AA66448822F9C4BC1&type=sim](http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ_RCIN=2902865&CFID=4841517&CFTOKEN=36607749&jsessionid=4230a23a610a1d502b1b&q=D8ADA706294D946AA66448822F9C4BC1&type=sim) (Accessed January 2008).

work was directed at water applications, where the noise environment is particularly challenging.<sup>27</sup>

- **Multi-agent robot systems for industrial applications in the transport domain.** This effort was a cost-sharing program funded at a modest level (€ 245,000) by the EU. The objective of this effort was to define a generic approach to multi-agent mobile robot transport systems for intelligent manufacturing. It involved several major research universities/national institutes and one major industrial player, Mercedes Benz AG. The outgrowth of this work has applicability to transport and logistics applications.<sup>28</sup>
- **Autonomous mobile robotics applied to human augmentation (AMOR2HUMAN).** This small research project explores technologies for combining a mobile platform and an exoskeleton to provide rehabilitation therapy and functional assistance. The project is described as scientifically ambitious. It envisions a bio-inspired approach to control the exoskeleton and the mobile platform. This project is a multi-disciplinary effort that includes theoretical developments and integration on real systems. These developments are relevant to DoD primarily for soldier systems.<sup>29</sup>

## **b. NATO Efforts**

Although NATO does not directly fund or conduct R&D efforts, it does form groups to monitor and coordinate technological developments in key areas and to develop standards to improve the interoperability of NATO forces.

The North Atlantic Treaty Organization Research and Technology Organization (NATO RTO) claims to be the largest collaborative research body in the world. It conducts research and exchanges technical information among its 26 nations and 38 partner countries. NATO RTO has several research activities related to UGVs. Research

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<sup>27</sup> Community Research and Development Information Service (CORDIS). Available: [http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ\\_RC�=1820749&CFID=4841517&CFTOKEN=36607749&jsessionid=423014214db7773c4f75&q=0CE122AC6BA4613002BBDDBFACD0E45&type=sim](http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ_RC�=1820749&CFID=4841517&CFTOKEN=36607749&jsessionid=423014214db7773c4f75&q=0CE122AC6BA4613002BBDDBFACD0E45&type=sim) (Accessed January 2008).

<sup>28</sup> Community Research and Development Information Service (CORDIS). Available: [http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ\\_RC�=2007228&CFID=4841517&CFTOKEN=36607749&jsessionid=423014214db7773c4f75&q=C4EA1AFD36E68CF94532919C8E16A073&type=sim](http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ_RC�=2007228&CFID=4841517&CFTOKEN=36607749&jsessionid=423014214db7773c4f75&q=C4EA1AFD36E68CF94532919C8E16A073&type=sim) (Accessed January 2008).

<sup>29</sup> European Union Research Project Reference: 39284. Autonomous mobile robotics applied to human augmentation (AMOR2HUMAN): Available: [http://cordis.europa.eu/fetch?CALLER=FP6\\_PROJ&ACTION=D&DOC=1&CAT=PROJ&QUERY=1203600579117&RC�=83097](http://cordis.europa.eu/fetch?CALLER=FP6_PROJ&ACTION=D&DOC=1&CAT=PROJ&QUERY=1203600579117&RC�=83097) (Accessed January 2008).

interests include materials, power sources, sensors, control, systems integration, human-system interaction, multi-system coordination, and battlefield applications.<sup>30</sup>

A current Research Task Group (RTG) is the Military Applications for Multi-Robot Systems (IST-058/RTG-024). It focuses on teams of UGV, unmanned aerial vehicles (UAV), and unmanned underwater vehicles (UUV) that can be fielded in the short term. Research interests include level of autonomy, human-machine interaction, human factors, distributed artificial intelligence (AI), testing and validation, and collective, collaborative, and cooperative behavior. Potential applications include reconnaissance, surveillance, and target acquisition (RSTA), demining and EOD, NBC decontamination, security, sniper detection, decoy and deception, precision strike, transport, rescue, and sensor and communication networks. This RTG also helps organize the biennial European Land Robot Trials and the Workshop on Multi-Robot Systems.<sup>31</sup>

In the area of standards, the primary focus for unmanned systems has been NATO Standardization Agreement (STANAG) 4586, *Standard Interface of the Unmanned Control System (UCS) for NATO UAV Interoperability*, established in 2002. STANAG 4586 has been widely adopted for UAV and has also been applied to other types of unmanned systems. Within DoD, JAUS is the standard for ground robotics development.<sup>32</sup>

JAUS is arguably well positioned to become an international standard:

- As a practical matter, the United States is by far the largest market for military UGV, and DoD has mandated the use of JAUS.
- In terms of positive developments, JAUS has been adopted by SAE International as SAE AS-4S, which provides impetus for acceptance within a substantial (but not universal) community. (It appears that only the United Kingdom, among our close allies, is involved in SAE.)
- The perception of JAUS as a U.S. DoD-mandated standard should be offset by DoD initiatives for use of non-proprietary and open-architecture common control systems. This should allow the use of JAUS as an open standard (perhaps with DoD-unique extensions). If so, this will increase its acceptability as an international standard.

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<sup>30</sup> NATO RTO Web Site: <http://www.rta.nato.int/> (Accessed January 2008).

<sup>31</sup> FGAN Web Site. NATO RTG. Available: [http://www.fgan.de/~natoeuro/index\\_nato.html](http://www.fgan.de/~natoeuro/index_nato.html) (Accessed January 2008). Also, see [http://www.rta.nato.int/Activity\\_Meta.asp?Act=IST-058](http://www.rta.nato.int/Activity_Meta.asp?Act=IST-058) (Accessed January 2008).

<sup>32</sup> Pedersen, Jorgen. Interoperability standards: A current and future look at C2 interoperability standards. *Unmanned Systems Interoperability Conference*, October 31, 2007.

- Finally, although examples of JAUS's use outside the United States are few, experience within DoD and the apparent success of South Korean developers in implementing the standard without extraordinary effort offer promise for NATO acceptance of JAUS.

### **c. European Land-Robot Trial (ELROB) Efforts**

NATO and the European Robotics Network (EURON) sponsor the ELROB in collaboration with the German Armed Forces. German defense experts state that the ELROB is an important venue to showcase potential ideas for the BMVg (and other foreign military organizations), and ELROB is said to be the primary window into Europe's state-of-the-art military UGV capabilities and leading-edge UGV R&D activities. While ELROB is an annual event, the focus alternates each year between civilian (C-ELROB) and military applications (M-ELROB). The trials are open to teams from the European continent (including Russia). The first trial in 2006 had 20 participants from 5 European countries. Participants included Rheinmetall Landsysteme GmbH (Germany), QinetiQ (United Kingdom), the Ecole Polytechnique Fédérale de Lausanne (EPFL) (Swiss Federal Institute of Technology – Lausanne) and MacroSwiss (Switzerland), the Przemyslowy Instytut Automatyki i Pomiarów (PIAP) (Industrial Research Institute for Automation and Measurements) (Poland), and IdMind (Portugal).<sup>33, 34</sup>

## **2. Canada**

Canada supports substantial research efforts in robotics. Areas of work include autonomous systems, especially in sensors and integration, control systems for robotic applications, data communications systems, and vehicle platforms. Enabling areas include AI and the ergonomic aspects of man-machine interface. Defence R&D Canada (DRDC)<sup>35</sup> is encouraging the military use of robotics.

DRDC Suffield,<sup>36</sup> one of seven Department of National Defence (DND) research centers in Canada, is the main governmental body in robotics research. It is developing remotely controlled UGV for EOD/NBC detection and monitoring. Researchers report

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<sup>33</sup> ELROB Web Page: <http://www.fgan.de/~elrob2006/MELROB/2008/organisers.html> (Accessed January 2008).

<sup>34</sup> ELROB Home Page: (<http://www.m-elrob.eu/>) (Accessed January 2008).

<sup>35</sup> DRDC is an agency of the Department of National Defence (DND). Its purpose is to respond to the scientific and technological needs of the Canadian Forces (CF).

<sup>36</sup> See [http://www.dres.dnd.ca/Home/index\\_e.html](http://www.dres.dnd.ca/Home/index_e.html) (Accessed January 2008).

work in developing robotic platforms to test software/robot mobility issues, such as overcoming obstacles. Other work includes robot communications and multi-robot teams.

Canada currently operates the Improved Landmine Detection System (ILDS), which was developed by General Dynamics Canada (see Figure III-1). This system is based on the DRDC mine-detection robot developed in the 1990s.<sup>37</sup> The ILDS is designed to detect, track, and mark buried anti-tank mines on roads, tracks, and other prepared surfaces. The system comprises two main vehicles, the Protection Vehicle (PV) (see Figure III-1a), and the Remote Detection Vehicle (RDV) (see Figure III-1b), with tele-operation of both capable from any configured support vehicle platform. The PV is an M113 armored personnel carrier (APC) equipped with a mine plough, infrared (IR) imager, magnetic metal detectors, and a marking system. The RDV also has IR imaging and metal detectors but adds GPR and a confirmation system that uses thermal neutron analysis to detect the nitrogen content found in all landmine explosives.

Several publicly traded companies operate in Canada in the robotics field:

- Allen-Vanguard Corporation: remotely operated vehicles (ROV) for bomb disposal and counterterrorism
- Braintech Inc: robotic vision systems
- MDA Space Missions of MacDonald, Dettwiler, and Associates: space robotics, autonomous ground vehicles, and planetary rovers.

Several other companies are active in developing robotic systems that have potential for military applications. These companies include Engineering Services Inc. (ESI), Frontline Robotics, Applied AI Systems, Inc. (AAI), and CDL Systems Ltd.

Frontline Robotics advertises a range of mobile robotic solutions for homeland security and commercial security applications. It describes a “core technology,” called Robot Open Control™ (The ROC™), which is a robot operating system that provides autonomy and cognitive collaboration for teams of mobile robots. It advertises a patented Team Intelligence architecture designed to provide security forces improved situational awareness. This architecture is also intended to effect a coordinated response to security

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<sup>37</sup> CBC News Report. July 2007. Military robots: Where robots are serving now and will they ever pull the trigger?. Available: <http://www.cbc.ca/news/background/tech/robotics/military.html> (Accessed January 2008).



(a) The PV



(b) The RDV

**Figure III-1. The Improved Landmine Detection System (ILDS)**

breaches. The list of on-board sensors includes GPS, inertial navigation, and lasers and radar “to help robots perceive their position, pose and progress relative to known maps and objectives,” and for obstacle avoidance and anomaly detection.<sup>38</sup>

CDL Systems Ltd. produces a Vehicle Control Station (VCS) for command and control (C2) of unmanned vehicles. The system can be used for real-time coordination and control of multiple unmanned ground, sea, and air vehicles in applications such as surveillance and mine clearance. The station can be used from moving platforms, and multiple VCS systems can be networked. The VCS is designed to interface with existing control hardware, communications systems, and off-the-shelf computer platforms.<sup>39</sup>

Much of Canada’s robotics R&D seems to take place in academia. McGill University’s Centre for Intelligent Machines (CIM)<sup>40</sup> is recognized as a Center of Excellence for intelligent systems, robotics, vision, speech recognition, and systems and control. The center collaborates with other research institutions. For example, McGill researchers worked with researchers at the University of Michigan and University of California at Berkeley to develop the hexapedal robot (RHex) circa 2000. More recently, they

<sup>38</sup> Frontline Robotics Web Page. Robotics Technology. Available: <http://www.frontlinrobotics.com/RoboticsTechnology/roc.htm> (Accessed January 2008).

<sup>39</sup> CDL Systems Web Site: <http://www.cdlsystems.ca/> (Accessed February 2008).

<sup>40</sup> See <http://www.cim.mcgill.ca/> (Accessed January 2008).



established the Centre REPARTI, a Strategic Team for the Study of Distributed Intelligent Environments, with Laval University in 2006.<sup>41, 42</sup>

### 3. France

The French MoD has been active in UGV for military applications. Efforts date from the early 1980s. Since 2003, robotics has been a major part of the French Network-Enabled Capability (NEC) program.<sup>43</sup>

The SYstème Robotisé d'Acquisition pour la Neutralisation d'Objectifs (SYRANO) (Robotic system for acquisition and neutralisation of targets) (see Figure III 2a) demonstration program was completed in 1999. It was developed by Cap Gemini Division ITMI (now CGEY), Dassault Electronique (now Thales Airborne Systems), Giat Industries, and Sagem Défense Sécurité. It was based on the Wiesel-2 tracked vehicle (see Figure III-2b) and is designed for reconnaissance and surveillance applications. While not produced or fielded in numbers, this design is still referenced as a prototype and test bed.



Figure III-2a. SYRANO Battlefield Robot



Figure III-2b. Wiesel-2 Tracked Vehicle

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<sup>41</sup> McGill Reporter News Page. Building a better robot. Available: <http://www.mcgill.ca/reporter/32/18/buehler/> (Accessed January 2008).

<sup>42</sup> McGill Centre for Intelligent Machines. Annual report 2005–2006. Available: <http://www.cim.mcgill.ca/research/05-06AnnualReport.pdf> (Accessed January 2008).

<sup>43</sup> Joint Robotics Program Master Plan (JRPMP). FY 2005.

The French Armed Forces has interest in weapons, autonomy, and night vision and electronic sensors related to robots, particularly for countermine and demining applications. The tank-based AMX30B2DT minefield breacher built by Giat Industries is an example of a UGV for countermine operations. The remotely controlled robot passed its testing in 2005, and plans for procurement of 10 tele-operated systems are reported.

For advanced concepts for robotic operations, Thales is heading a consortium to develop the Bulle Opérationnelle Aéroterrestre (BOA) (French Air/Land Operational Bubble networked air-land warfare concept) demonstrator (see Figure III-3). BOA, a € 144-M, 7-year French defense procurement effort, is a network-enabled, close-combat system. BOA introduces new concepts of net-centric warfighting with existing and future forces, as it ties together all the assets in the air-land theatre, including land vehicles, sensors, UAVs and infantry in mounted and dismounted formations. Integration of robotics is a major part of the effort. Planning started in 2000, and work commenced in 2005.



**Figure III-3. Artist's View of the BOA Concept**

Other BOA project participants include Groupe SAGEM, Giat Industries, the European Aeronautic Defence and Space Company (EADS), and MBDA (jointly owned by BAE Systems, EADS, and Finmeccanica).<sup>44</sup> The € 144-M budget appropriation does not provide a breakdown showing the amount of funding that will be dedicated to UGV. However, initial planning documents identified ground robots as a significant focus of the effort and cited a figure of € 10M for 10 teleoperated AMX 30 tanks and € 8M for

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<sup>44</sup> Projet de loi de finance pour 2008. Defense-Environnement et soutien de la politique de defence. (Finance Bill for 2008. Defense-Environment and support for defence policy). Available: <http://www.senat.fr/rap/a07-094-7/a07-094-71.html> (Accessed January 2008).



image processing to support increased autonomy and improved teleoperation.<sup>45</sup> These efforts comprise only part of the planned effort (and by logical extension, probable investment) in ground robotics.

As part of the BOA and in support of advanced integrated soldier systems, France has been pursuing a family of smaller robots under the Mini-Robots de Choc (MiniROC) program. This is a family of vehicles (see Figures III-4a–4c) is primarily intended for use by dismounted soldiers in assault missions, with an emphasis on urban operations. The family of systems features three complementary designs:

1. A manportable UGV called the Petit Robot Modulaire (PRM) (see Figure III-4a)
2. A somewhat larger (130-kg), wheeled, articulated UGV known as Robot Eclaireur Reconnaissance (REC) (see Figure III-4b)
3. The smallest of the MiniROC vehicles, a 2.1-kg Inbot Mini Robot Specialise (MRS) developed for reconnaissance in confined areas such as inside buildings and tunnels and underneath vehicles (see Figure III-4c).<sup>46</sup>

The Laboratoire d'Intégration des Systèmes et des Technologies (LIST) (Laboratory for Systems Integration and Technology) of the Commissariat à l'Énergie Atomique (CEA) (French Atomic Energy Commission), is a Center of Excellence for robotics. Research interests include man-machine interfaces, the mechanical design of complex systems, novel actuators, and intelligent control. The Interactive Robotics Unit includes engineers, technicians, and students, a Mesorobotics and Robotics Laboratory, and a Cobotics and Telerobotics Laboratory. The laboratory also conducts research concerning sensors and signal processing, with potential application to robotics.

Other French R&D activities involved in EU programs include

- Robosoft S.A.
- Centre National de la Recherche Scientifique (CNRS) (National Scientific Research Centre): Laboratoire d'Analyse et d'Architecture des Systemes (LAAS) (Laboratory for Analysis and Architecture of Systems)<sup>47</sup>
- Cybernetix SA: Ingénierie des Systèmes Automatiques et Robotiques

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<sup>45</sup> Delegation Generale Pour L'Armement (DGA) (General Delegation for Ordnance) Press Release. 6 June 2002. Project BOA (Bulle Operationelle Aero terrestre).

<sup>46</sup> Defense Update Web Page. MiniRoc. Available: <http://www.defense-update.com/products/m/miniROC.htm> (Accessed January 2008).

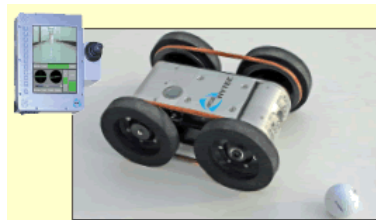
<sup>47</sup> See <http://www2.laas.fr/laas/2-4257-Home.php> (Accessed February 2008).



(a) The PRM



(b) The REC



(c) The MRS

**Figure III-4. Examples of MiniRoc Products**

- Sony France S.A.
- Université de Poitiers: Laboratoire de Mécanique Solides (LMS) (University of Poitiers: Laboratory of Solids Mechanics)<sup>48</sup>
- Centre de Robotique Intégrée d'Ile de France (CRIIF)
- Ecole Centrale Nantes:<sup>49</sup> Institut de Recherche en Communication et Cybernétique de Nantes (IRCCyN)<sup>50</sup> (Research Institute of Communication and Cybernetics of Nantes).

#### 4. Germany

Germany has had a national UGV effort since the 1980s and is a world leader in off-road UGV technologies. It has notable capabilities in perception, intelligent control, autonomous robotic vehicles, and human interface and planning.

<sup>48</sup> See <http://www-lms.univ-poitiers.fr/index.php?lang=en> (Accessed February 2008).

<sup>49</sup> École centrale de Nantes is one of the leading French Grandes écoles of engineering. The *Grandes écoles* (literally Grand Schools or Elite Schools) of France are higher education establishments outside the mainstream framework of the public universities system.

<sup>50</sup> See [http://www.ec-nantes.fr/LIRCC/1/fiche\\_structure/](http://www.ec-nantes.fr/LIRCC/1/fiche_structure/) (Accessed February 2008).

Germany's national Program for Intelligent Mobile Unmanned Systems (PRIMUS) (1993–2003) was managed by the Bundesamt für Wehrtechnik und Beschaffung (BWB) (Federal Office for Defence Technology and Procurement). EADS Dornier GmbH led the development of a UGV based on the Wiesel-2 tracked vehicle (see Figure III-2b). Variants explored include an autonomous scout vehicle using LADAR at a rate of four frames/second and an ROV using visible and IR cameras.<sup>51, 52</sup>

According to the JRPMP for FY 2005, the German robotics S&T effort is now under the Wehrtechnische Dienststelle für Informationstechnologie und Elektronik (WTD 81) (a Bundeswehr Technical Center for Information Technology and Electronics), with the BWB maintaining an oversight role.

A recent update on the German military's current UGV military capabilities and near-term R&D efforts asserts that the German military does not have any established requirements or Concept of Operations (CONOPS) for military UGV outside the mostly traditional unexploded ordnance/explosive ordnance disposal (UXO/EOD) missions. The broader potential uses for UGV, such as RSTA, logistic resupply, weapon platforms, the Multi-function Utility/Logistics and Equipment (MULE), and so forth, have not yet clearly evolved.<sup>53</sup>

The German MoD's most recent activities for existing military UGV capabilities include 2 major procurement initiatives that were undertaken during the past 24 months. Both were for EOD applications, including one solicitation for a large EOD robot and a second solicitation for a small EOD robot. The latter robot was addressed as an Urgent Operational Need for a COTS solution (PackBot) provided through a \$50-M (USD) contract with iRobot Corporation. Competing firms included TELEROB Gesellschaft für Fernhantierungstechnik mbH (Germany), Allen Vanguard (Canada), PW Allen (United Kingdom, now part of Allen Vanguard), PIAP (Poland), and Eod Performance, Inc. (United Kingdom, now part of Allen Vanguard).

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<sup>51</sup> EADS News Page. Robotic vehicle Primus does not require a driver. Available: [http://www.eads.com/1024/es/pressdb/archiv/2004/2004/Defence%20and%20Security%20Systems/es\\_20040121\\_primus.html](http://www.eads.com/1024/es/pressdb/archiv/2004/2004/Defence%20and%20Security%20Systems/es_20040121_primus.html) (Accessed January 2008).

<sup>52</sup> PRIMUS: Autonomous driving robot for military applications (Abstract). Proceedings of SPIE, *Unmanned Ground Vehicle Technology II*, July 2000. Available: <http://spiedl.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=PSISDG004024000001000313000001&idtype=cvips&gifs=yes> (Accessed January 2008).

<sup>53</sup> Karvonides, N., IDA. Telecom interviews with the Counselor for Defense Cooperation (Technology) at the Embassy of the Federal Republic of Germany in Washington, DC, and an SME at the BMVg. 2007.

TELEROB (formerly owned by Rheinmetall Defense) competed and won a separate procurement contract for Germany's large EOD UGV called the telerob Explosive Ordnance Disposal and observation robot (tEODor).

The German MoD (i.e., BMVg) is actively supporting military UGV technology evaluation of mature industry technology for demonstrating future possible uses for military UGV [i.e., potential CONOPs, tactics, techniques, and procedures (TTP)] for RSTA, logic resupply, and CBRN EOD missions. In 2007, BMVg had 5 UGV R&D programs that are developing six different vehicles in four basic categories (see Figure III-5) for RSTW, CBRN/EOD, and logistic resupply missions. These programs are not new technology "development" initiatives but rather demonstration and evaluation of mature technologies available from Germany, Canada, and possibly Israel. BMVg's technical priorities for these demonstration efforts include human interface; multi-robot networking and increased autonomy, and improved counter CBRN/EOD capability.<sup>54</sup>



**Figure III-5. German Technology Demonstrators**

<sup>54</sup> Karvonides, N., IDA. Telecom interviews with the Counselor for Defense Cooperation (Technology) at the Embassy of the Federal Republic of Germany in Washington, DC, and an SME at the BMVg. 2007.

The MoD also continues to be interested in military robotics S&T and is investigating the use of small robots with military forces and the transfer of the PRIMUS-D technologies to other platforms and systems. In addition, Germany is also showing an increased interest in man-portable robots.

The German Armed Forces sponsors an annual ELROB Trial to showcase the state of the art in European UGV. The focus alternates each year between civilian (C-ELROB) and military (M-ELROB) applications. The trials are open to teams from the European continent (including Russia). The first trial took place in 2006 and had 20 participants from 5 European countries. Participants included Rheinmetall Land-systeme GmbH (Germany), QinetiQ (United Kingdom), EPFL and MacroSwiss (Switzerland), and IdMind (Portugal).

The non-profit Fraunhofer-Gesellschaft (Fraunhofer Society), Germany's largest contract research organization, conducts robotics research at several research institutes, including the Institut Produktionsanlagen und Konstruktionstechnik (IPK) (Production Systems and Design Technology) and the Institut Intelligente Analyse- und Informationssysteme (IAIS) (Institute for Intelligent Analysis and Information Systems).<sup>55</sup> Research interests include kinematic controls, machine vision, sensor fusion, robot behavior, cooperative systems, adaptive control techniques, microelectronics, and autonomous manipulation, localization, and navigation.

In enabling technologies, Germany has a strong infrastructure that has the mechanical engineering and control systems expertise needed to conduct advanced work. Germany arguably has been the leader in the application of image understanding to ground vehicle navigation, guidance, and control. However, this work was directed toward navigation in much more structured road and highway conditions. Daimler Benz is a leader in these technologies.

Under an EU consortium, Daimler Benz led a multi-year commercial effort to show a semi-truck based leader-follower capability (program name was CHAUFFEUR). In addition to systems work, German industry is a world leader in commercial LADAR systems. This includes SICK/Ibeo and Z+F, which are used worldwide for proximity

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<sup>55</sup> In 2006, the Fraunhofer IAIS was founded as a merger between the Institut Autonome Intelligente Systeme (AIS) (Institute for Autonomous Intelligent Systems) and the Institute Medienkommunikation (IMK) (Institute for Media Communication).

sensing and are quite often used in R&D for low-cost, LADAR-based perception sensing for UGV.<sup>56</sup>

The Abteilung Bildverstehen Institut für Parallele und Verteilte Systeme (IPVS), Universität Stuttgart (Image Understanding Department of the Institute of Parallel and Distributed Systems, University of Stuttgart) has a program called Cooperative Mobile Robot Systems Stuttgart (CoMRoS). This program applies image understanding to formation driving and cooperative transport. This effort is directed toward operations in a complex environment entailing realistic safety requirements.

Other German research and academic institutions noted as active in EU-sponsored robotics R&D are

- Fraunhofer-Gesellschaft Institut Produktionstechnik und Automatisierung (IPA) (Institute for Manufacturing Engineering and Automation)
- J. Schmalz GmbH
- Forschungszentrum Informatik (FZI) an der Universitaet Karlsruhe, Interaktive Diagnose und Service Systeme (IDS) (Center of Research at the University of Karlsruhe, Interactive Diagnosis- and Services Sytems).

### **German–French Joint Development Efforts**

In 2003, the governments of France and Germany awarded a joint contract to Rheinmetall Landsysteme GmbH (Germany), MBDA France, and Thales (France) for the development of a vehicle-based, close-in countermine system technology demonstrator. The objective of this program, known as MMSR-SYDERA, is to show that meeting joint operational requirements for fast route opening, sensitive route opening, and area clearing is possible and that this cooperation can translate into a full-scale development program. The MMSR-SYDERA countermine system combines two modes of countermine operation, including triggering mines at a safe distance or detecting mines with sensors for low-order clearing. Thus MMSR-SYDERA system will consist of five different vehicles including both manned and unmanned vehicles. After industrial system trials in the second half of 2006, customer's evaluations of the system were scheduled for 2007.

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<sup>56</sup> IVSource News Page. Chauffeur shows off: demos of electronic tow-bar functions dazzle crowd in Italy. Available: [http://ivsourcenet.net/archivep/2003/jun/030614\\_chauffeur2.html](http://ivsourcenet.net/archivep/2003/jun/030614_chauffeur2.html) (Accessed January 2008).

Full-scale production and fielding is planned for 2009/2010 or later (depending on the reference).<sup>57, 58</sup>

A more recently identified Franco-German program is Artist (advanced real-time integration system testbed), which is slated for 2009. Artist will focus on the preparation and execution of four operational scenarios: coordinated fire management, remote control of unmanned vehicles, dismounted infantry operations, and distributed simulation. Companies taking part include Diehl BGT Defense (Germany) and Nexter, Sagem Défense Sécurité, and Thales (France).<sup>59</sup>

## 5. Japan

Although Japan is generally recognized as a world leader in robotics, it has had a relatively small effort in military unmanned systems. Japan's absence in this area may, in part, reflect a conclusion of Japanese planners that the lack of an established export market for military systems puts them at an unacceptable competitive disadvantage. Unmanned systems are featured prominently in recently released (April 2007) military planning documents.<sup>60</sup> The uses envisioned for ground robots are limited to ISR and traditional security and improvised ordnance countermeasure roles. However, one area of the current planning documents indicates a potential leap ahead: the implementation of operational systems comprising "large numbers of robots" within a relatively short time-frame (5 to 10 years).

A consideration that lends credibility to Japan's ambition in robotics is the significant effort directed toward cooperative performance developed in such Japanese-led competitions as RoboCup. Such efforts indicate a substantial capability to field sophisticated systems of military robots if the Japanese MoD decides to pursue development.

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<sup>57</sup> Defense Update Page on the Defense Update Page. MMSR - SYDERA, Issue 2, Year 2006. Available: <http://www.defense-update.com/products/m/mmrs-sydera.htm> (Accessed January 2008).

<sup>58</sup> Defense Update Page. MDA SOVIM-2 mine clearing systems. Issue 4, Year 2004. Available: <http://www.defense-update.com/products/s/souvim.htm> (Accessed January 2008).

<sup>59</sup> Defense Technology International. September 2007. Traffic signals: Network-centric vehicles touted for tactical operations. Available: <http://www.nxtbook.com/nxtbooks/aw/dti0907/index.php?startpage=27&PHPSESSID=ae6fcfd20b0eb26a31e6d9b69888d647&ncd=content> (Accessed January 2008).

<sup>60</sup> Technical Research and Development Institute (TRDI) of the Japanese MoD. April 2007. *Medium to Long-Term Defense Technology Outlook*.



Japan has exceptional infrastructure capabilities in many aspects of UGS. Much of this capability, however, is directed toward the development of humanoid robots and what may be termed novel and exotic applications. Examples of the latter include a modular robotic system developed by the Intelligent Systems Research Institute (ISRI) of the National Institute of Advanced Industrial Science and Technology (AIST). This robot can reconfigure itself for different forms of locomotion, including serpentine and quadrupedal.<sup>61</sup> Major Japanese corporations, such as Honda, Sony, and Toyota, have significant research efforts in humanoid robotics that include such well known products as ASIMO (officially an acronym for Advanced Step in Innovative MObility), QRIO (short for Quest for Curiosity), and in the past, AIBO (short for Artificial Intelligence roBOt).

Omron Corporation, in collaboration with U.S.-based Tmsuk Co., Ltd. (pronounced “Temzack”), has reported joint development of a machine-to-machine (M2M) robot system that can be remotely operated using an International Mobile Telecommunications-2000 (IMT-2000) third-generation (3G) mobile communications service. With an IMT-2000 wireless module installed in the robot, remote control is possible through the Internet from IMT-2000 terminals. The robot is advertised as having “five human senses” and is equipped with various sensors for surveillance. The information collected from the sensors helps with awareness of conditions in the targeted area.

## **6. United Kingdom**

Relative to other leaders in this field, the United Kingdom has produced only a few different systems. However, it has extensive capabilities in several key enabling technologies.

The United Kingdom’s current military UGV capabilities are similar to those of Germany. Like Germany, the United Kingdom uses military UGV primarily for traditional UXO/EDO requirements and recently sponsored two major procurement initiatives for next-generation UXO/EDO robots, including large and small robots.

For the smaller system, the UK MoD is funding (€ 65M or ~ \$95M USD) the development and future production of the 80 CUTLASS robots, to replace the Wheelbarrow EOD robot. CUTLASS is being developed by Remotec UK Ltd. (now a UK

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<sup>61</sup> AIST Web Page. Modular transformer robots. Available: <http://unit.aist.go.jp/is/dsysd/mtran3/> (Accessed January 2008).



subsidiary of Northrop Grumman)<sup>62</sup>, which also produces the Wheelbarrow. QinetiQ will supply the C2 system. The plan calls for deliveries in 2010. The prototype is a six-wheeled, modular UGV with a range of payloads, sensors, and tools, including a manipulator arm with a gripper that has nine degrees of freedom. Figure III-6 shows the wheeled CUTLASS and tracked Wheelbarrow systems.



**(a) CUTLASS**



**(b) Wheelbarrow**

**Figure III-6. Examples of UK EOD Robots**

QinetiQ appears to treat image understanding<sup>63</sup> as a pervasive enabling capability for systems, including vehicle control and robotics and sensors. While explicit references were not found to machine vision and image understanding, the general descriptions of QinetiQ's areas of expertise and the nature of the systems applications give evidence of a sound, state-of-the-art, if not world-leading, capability.<sup>64</sup>

R&D in the United Kingdom is distributed among government, industry, and academia. The following companies and organizations have been active in EU-funded robotics R&D:

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<sup>62</sup> Northrop Grumman. New Releases. Available: [http://www.irconnect.com/noc/press/pages/news\\_releases.html?d=110849](http://www.irconnect.com/noc/press/pages/news_releases.html?d=110849) (Accessed January 2008).

<sup>63</sup> Image understanding is a research area concerned with the design and experimentation of computer systems that integrate explicit models of a visual problem domain with one or more methods for extracting features from images and one or more methods for matching features with models using a control structure (i.e., the process of interpreting regions/objects in an image to figure out what's actually happening in that image).

<sup>64</sup> WTW OEI analysis (see Footnote 8).

- University of Leeds, School of Mechanical Engineering (prime contractor)<sup>65</sup>
- BAE Systems (Operations) Ltd, Advanced Technology Centres – Sowerby
- Thales Communications, Technology Division
- Shadow Robot Company Ltd.
- Roboscience Ltd.
- University of Salford, School of Computing, Science, and Engineering
- QinetiQ Ltd.: Centre for Robotics and Machines
- Forward Industries Ltd.

For future unmanned systems, UK expertise in intelligent systems is notable. The University of Leeds appears frequently in compilations of AI and machine-intelligence-related activities. Image understanding, machine vision, natural language, and knowledge representation are noted as areas of expertise. Examples of other academic centers in this area include the Intelligent Systems Lab (ISL)<sup>66</sup> at Heriot-Watt University (Edinburgh, Scotland), the Centre for Intelligent Systems and their Applications (CISA)<sup>67</sup> at the University of Edinburgh, and the University College London (UCL).

The Visual Information Processing Lab (VIPLAB)<sup>68</sup> at the University of Nottingham reports work in machine learning and pattern recognition using neural networks and support vector machines. The Image Processing & Interpretation (IPI)<sup>69</sup> Research Group is investigating image processing and analysis, machine vision, and AI.

## **B. OTHER SIGNIFICANT CAPABILITIES**

### **1. Australia<sup>70</sup>**

The Defence Science and Technology Organisation (DSTO),<sup>71</sup> part of Australia's Department of Defence, supports the Australian Defence Force (ADF) in its activities (counter-terrorism, peacekeeping, and border protection). Recent emphasis on defense

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<sup>65</sup> See <http://www.engineering.leeds.ac.uk/mech/school/index.shtml> (Accessed February 2008).

<sup>66</sup> See <http://www.macs.hw.ac.uk/isl/> (Accessed February 2008).

<sup>67</sup> See <http://www.cisa.inf.ed.ac.uk/> (Accessed February 2008).

<sup>68</sup> See <http://www.viplab.cs.nott.ac.uk/> (Accessed February 2008).

<sup>69</sup> See <http://www.cs.nott.ac.uk/IPI/> (Accessed February 2008).

<sup>70</sup> See <http://www.cat.csiro.au/ict/staff/pic/aus-robot-research.htm> (Accessed February 2008).

<sup>71</sup> See <http://www.dsto.defence.gov.au/> (Accessed February 2008).

against terrorism and weapons of mass destruction (WMD) has increased interest in unmanned systems and robotics.

DSTO developed the Ground-based Weaponised Light Experimental Robot (GROWLER). It is a remotely controlled unmanned weapon systems test bed platform. The vehicle is based on the six-wheeled Polaris Ranger all-terrain vehicle (ATV). It features a Kongsberg remote weapon station with a 0.50-caliber machine gun.<sup>72</sup>

The Robot, Sensors, and Intelligent Environments Group of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) conducts research in the areas of robotics and intelligent systems and in biomedical imaging technologies.<sup>73</sup>

CSIRO's robotics research includes image and laser machine vision; automation/robotic control; mechanical, electrical, electronics and software systems engineering; and wireless sensor and actuator networks.

CSIRO's intelligent system research includes multi-component complex systems, machine learning, embedded networks, and distributed intelligence.

Most of CSIRO's technology (dual-use) research centers on civil applications.

Much of Australia's leading research is conducted under the auspices of the Australian Research Council (ARC) Centres of Excellence.<sup>74</sup> The ARC Centre of Excellence for Autonomous Systems was established in January 2003. It brings together three leading research groups:

- The Australian Centre for Field Robotics (ACFR) at the University of Sydney<sup>75</sup>
- The Artificial Intelligence and Mechatronics groups at the University of New South Wales (UNSW)<sup>76</sup>
- Mechatronics and Intelligent Systems Group at the University of Technology Sydney (UTS).<sup>77</sup>

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<sup>72</sup> Jane's. Australia's DSTO unveils weaponised robot. Available: [http://www.janes.com/news/defence/systems/jdw/jdw071026\\_2\\_n.shtml](http://www.janes.com/news/defence/systems/jdw/jdw071026_2_n.shtml) (Accessed February 2008).

<sup>73</sup> CSIRO Robot, Sensors and Intelligent Environments Group Web Site: <http://www.csiro.gov.au/science/intelligentenvironments.html> (Accessed February 2008).

<sup>74</sup> See [http://www.arc.gov.au/ncgp/ce/ce\\_default.htm](http://www.arc.gov.au/ncgp/ce/ce_default.htm) (Accessed February 2008).

<sup>75</sup> See <http://www.acfr.usyd.edu.au/> (Accessed February 2008).

<sup>76</sup> See <http://ai.cse.unsw.edu.au/index.html> and [http://www.mech.unsw.edu.au/content/plans/mechatronic/Mechatronics\\_Home.cfm?ss=12](http://www.mech.unsw.edu.au/content/plans/mechatronic/Mechatronics_Home.cfm?ss=12) (Accessed February 2008).

<sup>77</sup> See [http://www.eng.uts.edu.au/Research/areas\\_mis.htm](http://www.eng.uts.edu.au/Research/areas_mis.htm) (Accessed February 2008).

ARC funds the Centre, with significant financial contributions from the State Government of New South Wales and the three partner institutions. The Centre also receives contract research support from Australian and overseas companies.<sup>78</sup>

In addition, Monash University appears to have substantial involvement and expertise in enabling technologies for advanced robotics. The Intelligent Robotics Research Center research interests include 3D vision, virtual reality (VR), mobile robots, tactile perception. A more recent activity is the Aerobotics<sup>79</sup> aerial robotics program.

## 2. Austria

The Technische Universität Wien (Vienna University of Technology) conducts research into vision and control systems for mobile robots. The researchers have developed an approach to add extensible transport framework to a Common Object Request Broker Architecture (CORBA) system. The CORBA-based system allows real-time data and event communication without interference. One application is to simplify the complex functional control software of autonomous robots.<sup>80</sup>

The Technische Universität Wien also developed a novel vision system for its Tinyphoon<sup>81</sup> (see Figure III-7) robot in the Micro Robot World Cup Soccer Tournament (MiroSot). Tinyphoon reportedly is the world's smallest soccer-playing robot. This modular robot has a small camera, vision board, and sensor board.



**Figure III-7. Tinyphoon**

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<sup>78</sup> ARC Centre of Excellence for Autonomous Systems Web Page: <http://www.cas.edu.au/home.html> (Accessed February 2008).

<sup>79</sup> See <http://www.ctie.monash.edu.au/AEROBOTICS/> (Accessed February 2008).

<sup>80</sup> Vienna University of Technology Web Site. An extensible transport framework for CORBA with emphasis on real-time capabilities. Available: <http://www.vmars.tuwien.ac.at/php/pserver/extern/docdetail.php?DID=1396&viewmode=published&year=2004> (Accessed February 2008).

<sup>81</sup> See [http://publik.tuwien.ac.at/files/pub-et\\_12150.pdf](http://publik.tuwien.ac.at/files/pub-et_12150.pdf), pp. 55–66 (Accessed February 2008).

### **3. Belgium**

The Humanitarian Demining (HUDEM) program,<sup>82</sup> created by the Belgian Ministry of Defense (MoD), is a collaborative research project for mine sensors, sensor data fusion, minefield mapping, and mine detection and clearing robots. The participating universities are the

- Royal Military Academy (RMA) (Project Leader)
- Katholieke Universiteit Leuven (KUL) (Catholic University of Leuven)
- Universiteit Gent (UGent) (Ghent University)
- Universite Catholique de Louvain (UCL) (Catholic University of Louvain)
- Universite Libre de Bruxelles (ULB) (Free University of Brussels)
- Université de Liège (ULg) (The University of Liège)
- Vrije Universiteit Brussel.

Areas of research relevant to ground robotics include

- Multi-sensor data fusion
- Stereovision
- Dedicated robots, including legged robots, tracked robots, a wheeled robot called TRIDEM, and a remote controlled air excavation device called Blow Beetle.

### **4. China**

China's robotics research began during the 1980s. At that time, its resources were modest compared to those of other countries. Nonetheless, exposure to U.S. and Japanese robotic developments at the Expo '85 World Fair increased China's determination to accelerate its robotic R&D efforts.

Much of China's robotics research has focused on civilian applications. More recently, however, its scope of interest and activity appears to have expanded to the military sector. A recent report on Chinese Military Robotics notes that investment in defense-based robotics has increased over 200% since 2002. Major research activities in defense applications are identified at the National University of Defense Technology (NUDT), Shenyang Institute of Automation (SIA), and the Institute of Robotics at

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<sup>82</sup> Signal and Image Centre (SIC) Web Site. HUDEM. Available: <http://www.sic.rma.ac.be/Research/HumDem/Hudem/index.html> (Accessed February 2008).

Beihang University's (formerly Beijing Institute of Aeronautics) School of Mechanical Engineering and Automation.<sup>83</sup>

Although China is still trailing the state of the art in military robotics, its capabilities in industrial robotics are growing. This growth can be attributed to the country's large manufacturing base, especially in automotive manufacturing. Experts predict that China's robotic industry will reach more than 9.31B Renminbi<sup>84</sup> (~ \$1.3B USD) by 2010. One notable trend is the international robotics companies that are opening branches in China and forming partnerships with Chinese companies. For example, ABB Robotics (part of the ABB Group of Switzerland) moved its headquarters from Detroit to Shanghai. Another example is Adept Technology of the United States, which formed a partnership with Second2None Machine Vision Systems of China to distribute and integrate Adept's robots and vision systems in China.<sup>85, 86, 87, 88</sup>

The SIA at the Chinese Academy of Sciences (CAS) is a major Chinese developer of advanced robotics. The Institute's Robotics Laboratory<sup>89</sup> was formed in 1989. In 2003, they reported work on biomimetic fish robots with intelligent control systems using fuzzy control and neural networks. In addition, in 2003, they developed the WeiFu Robot (WFR), which was a tracked ground robot for explosive ordnance disposal, hazardous materials handling, and search and rescue (SAR) applications. It could carry a canister gun and tear gas bombs, toxic gas sensors, and high-pressure water guns. It could climb

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<sup>83</sup> Concurrent Technologies Corporation. July 2007. *Emerging technology weaponization Task 2: Robotics in China* (Unclassified/FOUO).

<sup>84</sup> The renminbi (literally, people's currency) is the currency of the mainland of the People's Republic of China (PRC).

<sup>85</sup> 2006 China Robot Expo. October 11–13 2006, Beijing International Convention Center: <http://www2.acae.cuhk.edu.hk/~iros06/docs/2006%20China%20Robot%20Expo.pdf> (Accessed January 2008).

<sup>86</sup> Trombly, Maria. September 2006. Robots follow china's auto growth. *Managing Automation Magazine* News Page. Available: [http://www.managingautomation.com/maonline/magazine/read/view/Robots\\_Follow\\_Chinas\\_Auto\\_Growth\\_12124170](http://www.managingautomation.com/maonline/magazine/read/view/Robots_Follow_Chinas_Auto_Growth_12124170) (Accessed on January 2008).

<sup>87</sup> Automation.com News Page. Adept signs robot rep in China. Available: <http://www.automation.com/store/p1030details23110.php?x=1&pagePath=00000000> (Accessed January 2008).

<sup>88</sup> Robotics Expert Group of the National High-Tech R&D Programme of China. Some new progress of advanced robotics in China. Report to the Joint Coordinating Forum 2003 (JCF'2003) of the International Advanced Robotics Programme (IARP). Available: [http://www.iai.csic.es/iarp/sapr/05\\_CHINA\\_IARP\\_JCF\\_2003.pdf](http://www.iai.csic.es/iarp/sapr/05_CHINA_IARP_JCF_2003.pdf) (Accessed January 2008).

<sup>89</sup> See <http://rlab.sia.ac.cn/english/Intro.asp> (Accessed January 2008).

stairs at a slope of less than 40° and travel at speeds of up to 0.5 m/s. Currently, the Robotics Laboratory lists work in distributed intelligent systems, microelectromechanical systems (MEMS) technology, and robots for hazardous tasks.

China is reportedly preparing to deploy a battlefield ground robot called Vanguard No. 1. In 2007, they demonstrated the wheeled robot with the Sichuan reserve militia in a mock hostage rescue mission. According to reports, the robot can conduct reconnaissance, attack, and defuse bombs. It can also be armed with a shotgun. They state that the remotely controlled robot travels at speeds of up to 2 m/sec. It is reported to use both ultrasonic and satellite positioning systems for navigation and control. It is also reported to be equipped with colored charge coupled device (CCD) cameras and an IR imaging system for tele-operation.<sup>90</sup>

## 5. Croatia

DOK-ING d.o.o., reportedly the largest private demining company in Croatia, is involved in humanitarian demining.<sup>91</sup> The company offers the remotely controlled MV-4 Mini Mine Clearing System, MV-10 Medium Double Tool Mine Clearing System, and MV-20 Heavy Double Flail-Tiller Mine Clearing System,<sup>92</sup> the Grizzly-1 EOD Robot,<sup>93</sup> and UXO disposal robots. They also offer the remotely controlled, tracked MVD Mini Dozer<sup>94</sup> for a variety of applications in mining, construction, and defense.

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<sup>90</sup> People's Daily Online News Page. May 2007. China-made robot joins the Army. Available: [http://english.people.com.cn/200705/31/eng20070531\\_379684.html](http://english.people.com.cn/200705/31/eng20070531_379684.html) (Accessed January 2008).

<sup>91</sup> See <http://www.armedforces-int.com/categories/mine-clearing-technology/doking-croatian-mechanical-application-humanitarian-mine-action.asp> (Accessed January 2008).

<sup>92</sup> See (MV-4) <http://www.armedforces-int.com/categories/mine-clearing-technology/mv4-mini-mine-clearing-system.asp> (Accessed January 2008).

See (MV-10) <http://www.armedforces-int.com/categories/mine-clearing-technology/dok-ing-mv-10-medium-double-tool-mine-clearing-system.asp> (Accessed January 2008).

See (MV-20) <http://www.armedforces-int.com/categories/mine-clearing-technology/mv20-heavy-double-flailtiller-mine-clearing-system.asp> (Accessed January 2008).

<sup>93</sup> See <http://www.armedforces-int.com/categories/mine-clearing-technology/grizzly1-eod-robot.asp> (Accessed January 2008).

<sup>94</sup> See <http://www.armedforces-int.com/categories/mine-clearing-technology/mvd-mini-dozer.asp> (Accessed January 2008).



DOK-ING has supplied robots to the Swedish MoD, the Irish Directorate of Engineering, the Croatian MoD, and Mechem Consultants (South Africa).<sup>95</sup> The United States Army procured the MV-4 to meet the Robotic Combat Support System (RCSS) program requirements. They have also deployed these systems in Afghanistan and Iraq.<sup>96</sup>

Another Croatian firm, Đuro Đaković Specijalna vozila Inc. (DDSV) (Duro Dakovic Special Vehicles),<sup>97</sup> produces a remotely controlled tracked, 14-ton mine clearance vehicle with midi-flail for disposing of anti-tank and anti-personnel mine, called the RM-KA-02.<sup>98</sup>

## 6. Finland

The Department of Automation and Systems Technology<sup>99</sup> at the Teknillinen korkeakoulu (TKK) (Helsinki University of Technology) is active in robotics research. The Automation Technology Laboratory has developed several mobile robots with legged, wheeled, rolling, rowing, and hybrid locomotion. Areas of particular emphasis include robotic societies, mobile robots, and robotics in space, underwater, or in poorly structured environments such as for forestry, construction, and mining. Much of the work has been directed toward industrial and marine/maritime applications.<sup>100</sup>

TKK has collaborated in several international ventures:<sup>101</sup>

- The Innovative Educational Concepts for Autonomous and Teleoperated Systems (IECAT) project, with American and European universities
- The PANORAMA project of ESPRIT II on advanced perception and navigation systems for autonomous applications

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<sup>95</sup> Army Technology Web Page. Dok-ing – remote-controlled mine clearance machines. Available: <http://www.army-technology.com/contractors/mines/dok-ing-usa/> (Accessed January 2008).

<sup>96</sup> Joint Ground Robotics Enterprise (JGRE). October 2006. Development and utilization of robotics and unmanned ground vehicles. JGRE Report to Congress.

<sup>97</sup> Duro Dakovic Special Vehicles Web Site: [http://www.ddsv.hr/index\\_eng.htm](http://www.ddsv.hr/index_eng.htm) (Accessed January 2008).

<sup>98</sup> See [http://www.ddsv.hr/razminirac\\_eng.html](http://www.ddsv.hr/razminirac_eng.html) (Accessed January 2008).

<sup>99</sup> See <http://as.tkk.fi/en/> (Accessed January 2008).

<sup>100</sup> TKK Automation Technology Laboratory Web Site: <http://automation.tkk.fi/> (Accessed January 2008).

<sup>101</sup> TKK Web Page. Field and service robotics. Available: <http://automation.tkk.fi/Research/FSR> (Accessed January 2008).



- The FFUSION program for fusion research, the International Thermonuclear Experimental Reactor (ITER) project to develop an inspection system for the plasma vessel
- The SHICO project funded by the EU's Basic Research in Industrial Technologies for Europe-Europe/America (BRITE-EURAM) for the development of an integrated ship control system
- The BRITE-EURAM project called the Remote Operated Tankers Inspection System (ROTIS) for the development of a small ROV for inspecting ballast tanks.

## 7. Israel

Israel—specifically through Elbit Systems, Israel Aerospace Industries (IAI), and Israel Military Industries (IMI)—has strong experience in the development and use of unmanned systems for military and national security applications.

IAI's developments include the Guardium unmanned security vehicle (USV), a perimeter security system (see Figure III-8). Described as a “next-generation” autonomous patrol vehicle based on the Tomcar ATV, Guardium is a high-speed vehicle with sensors to help navigate various types of terrain, cameras to report field data, and voice communication. Payload options include both lethal and non-lethal weapons. The Guardium system contains a C4I center that monitors and controls the vehicle's activity and continuously processes data. If needed, the commander can override automatic operations and assume direct control.<sup>102</sup>



**Figure III-8. IAI Guardium USV**

<sup>102</sup> IsraCast News Page. 2008. Highly mobile unmanned vehicles. Available: <http://www.isracast.com/articles/68.aspx> (Accessed January 2008).

Elbit Systems has introduced a portable ground vehicle for reconnaissance applications. The Versatile, Intelligent, Portable Robot (VIPeR) is an unmanned robot that is capable of climbing stairs and navigating other obstacles. It features an unusual hybrid conformation where the wheels can expand to function as tracks. The VIPeR was designed to carry a variety of payloads, including sensors and weapons [e.g., a forward-looking infrared (FLIR) day/night camera, an explosive detector, a 9-mm mini-Uzi, grenade reloader, and a robotic arm]. This man-portable robot measures  $18 \times 18 \times 9$  in. and weighs 25 lbs. Elbit developed the system for the Israeli Defence Forces (IDF) as part of the Portable Unmanned Ground Vehicle (PUGV) program.<sup>103</sup>



**Figure III-9. The VIPeR**

In 2005, the Elbit Systems introduced the AvantGuard wheeled UGV (see Figure III-10). The AvantGuard uses a sensor package to identify and avoid obstacles along a pre-planned route. The navigation system uses a Differential Global Positioning System (DGPS) system with three control levels. It also has front and rear cameras mounted on a pedestal for 360-deg observation and remote situational awareness. Along with the sensor payload, it can carry weapon systems, such as Elbit's remotely controlled 7.62-mm weapon station.<sup>104</sup>

These systems are semi-autonomous or remotely controlled, which is typical of Israeli UGVs. Israel seems to aim for more technical, mature operational systems for patrol and reconnaissance applications as opposed to higher-risk sensor-enabled unsupervised autonomous UGVs.

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<sup>103</sup> DefenceTalk.com News Page. Elbit systems VIPeR. Available: [http://www.defencetalk.com/news/publish/army/VIPeR\\_Small\\_Portable\\_Reconnaissance\\_Robot110010878.php](http://www.defencetalk.com/news/publish/army/VIPeR_Small_Portable_Reconnaissance_Robot110010878.php) (Accessed January 2008).

<sup>104</sup> Defense Update Web Page. AvantGuard: Patrol, surveillance, & recce autonomous unmanned ground vehicle (UGV). Available: <http://www.defense-update.com/products/a/avantguard.htm> (Accessed January 2008).



**Figure III-10. AvantGuard UGV**

InRob Tech Ltd. advertises itself as a leader in the field of advanced wireless and remote control systems. It has been active in various defense and national security programs. It also markets the Wasp/Hornet family of EOD systems, and are reported to be pursuing the development of a somewhat larger EOD robot, the Hornet MK-5 (see Figure III-11), based on this experience.<sup>105-106</sup>



**Figure III-11. EOD Robot: Hornet MK-5**

In academic research, the Robotics Laboratory of the Department of Mechanical Engineering at the Technion - Israel Institute of Technology reports work in parallel kinematic robot structures. These robots can handle a heavier payload-to-weight ratio

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<sup>105</sup> InRob Web Site: <http://www.inrobtech.com/> (Accessed January 2008).

<sup>106</sup> See [http://www.israeli-weapons.com/weapons/vehicles/engineer\\_vehicles/robots/Robots.html](http://www.israeli-weapons.com/weapons/vehicles/engineer_vehicles/robots/Robots.html) (Accessed January 2008).

than the more traditional chain or serial based robots. This work is primarily directed toward medical applications.<sup>107</sup>

## 8. Italy

Oto Melara, a member of the Finmeccanica Group, has been involved in UGV developments since 1986. It is reported to be engaged in UGV developments (either independently or in concert with others) on at least 7 UGV projects, ranging from a 5-ton tactical vehicle to a miniature manportable unit, the TRP 3, weighing 5.5 kg.<sup>108</sup>

The state of the art in Italian UGVs appears to the Praetor, a 240-kg wheeled UGV capable of carrying a 60-kg payload. The system is described as being powered by electric drive and having 6-hr endurance, with a top speed of 50 km/h (30 mph). The system has a line of sight control range of 10 km (1–2 km in urban terrain). The control link method was not described in the reference. An interesting aspect of the work at Oto Melara is that it explicitly includes armed attack variants in both the Praetor and the TRP 2, a smaller 110-kg vehicle that is capable of carrying larger (80-kg) payload than the Praetor.<sup>109</sup>

In the area of sensors and controls for autonomous vehicles, Galileo Avionica, (also a part of the Finmeccanica Group) has been involved in EU robotic R&D.<sup>110</sup>

Other work noted in Italy is largely confined to niche areas and to academia. The Robotics Group at the Centro Interdipartimentale di Ricerca “E. Piaggio,” Università di Pisa (Interdepartmental Research Center “E. Piaggio,” University of Pisa) has been a center for research in haptic systems. The center conducts fundamental and applied research into robotic hands and haptic sensing, displays and interfaces, and tools

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<sup>107</sup> Technion Robotics Laboratory Web Site: [http://robotics.technion.ac.il/Robotics\\_Main.asp](http://robotics.technion.ac.il/Robotics_Main.asp) (Accessed January 2008).

<sup>108</sup> Nativi, A. December 2007. Automation Army: UGVs meet a growing range of battlefield needs. Defense Technology International. Available: <http://www.nxtbook.com/nxtbooks/aw/dti1207/index.php?startpage=27> (Accessed February 2008).

<sup>109</sup> Nativi, A. December 2007. Automation Army: UGVs meet a growing range of battlefield needs. Defense Technology International. Available: <http://www.nxtbook.com/nxtbooks/aw/dti1207/index.php?startpage=27> (Accessed February 2008).

<sup>110</sup> To illustrate the challenge of following trends in global technology in this field, as of January 2008, Galileo Avionica merged with Selex Electronics SAS (United Kingdom) to form a new Finmeccanica subsidiary, SELEX GALILEO.

(specifically surgical tools). The researchers are developing VR haptics, simulation software aimed at investigating haptic interfaces using a mechanical system in VR.<sup>111</sup>

The Dipartimento di Informatica e Sistemistica (DIS) (Department of Computer and Systems Science) at the Sapienza Università di Roma (University of Rome La Sapienza) is active in researching the use of robotic agents in SAR operations. The department has significant AI expertise and a high level of competence in complex robotics. They have received Air Force Office of Scientific Research Grants in this area.<sup>112</sup>

Other Italian activities engaged in EU-funded robotic-related R&D include

- Università degli Studi di Catania, Dipartimento Elettrico, Elettronico, e Sistemistico (DEES) (University of Catania, Department of Electrics, Electronics, and System Engineering)
- D'Appolonia S.p.A.
- STMicroelectronics S.R.L.: Soft Computing and Nano-Organics Group
- Università degli Studi di Genova (University of Genova)
  - Laboratorio di Progettazione Meccanica Applicata alla Robotica Industriale (PMAR)<sup>113</sup> (Laboratory of Design and Measurement for Automation and Robotics)
  - Department of Mechanics and Machine Design

## 9. Poland

The Przemysłowy Instytut Automatyki i Pomiarów (PIAP)<sup>114</sup> (the Industrial Research Institute for Automation and Measurements) was established in 1965 as a national institute to develop new technologies, automation systems, and measuring equipment for various industries. It has participated in the recent ELROB competitions. Current work at the PIAP focuses on automation and robotization of production processes, automation of transport between operation stands, quality control systems, mobile robots, industrial measurement systems, measuring and inspection equipment, and car recycling. In 1992, it established a special section for projects relating to mobile robots:

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<sup>111</sup> Interdepartmental Research Center E. Piaggio. Robotics Group Web Site: <http://www.piaggio.ccii.unipi.it/newrobotics/roboticresearch.html> (Accessed January 2008).

<sup>112</sup> AFOSR Grant Contract, Transaction Number 014030E;  
AFOSR Grant Contract, Transaction Number 063016.

<sup>113</sup> See <http://www.dimec.unige.it/PMAR/> (Accessed February 2008).

<sup>114</sup> PIAP Web Site: <http://www.piap.eu/index.php> (Accessed February 2008).

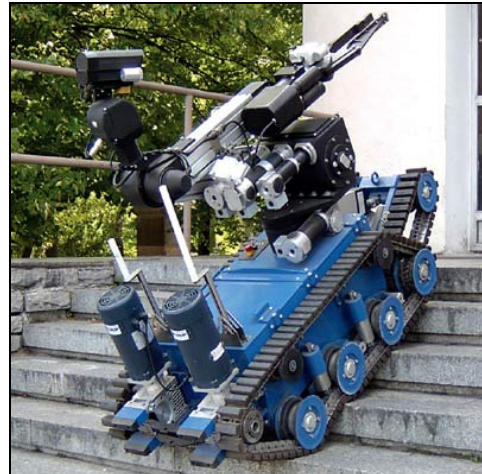


The Intelligent Mobile Systems Division. Since 1996, its technology has been adapted for antiterrorist applications.

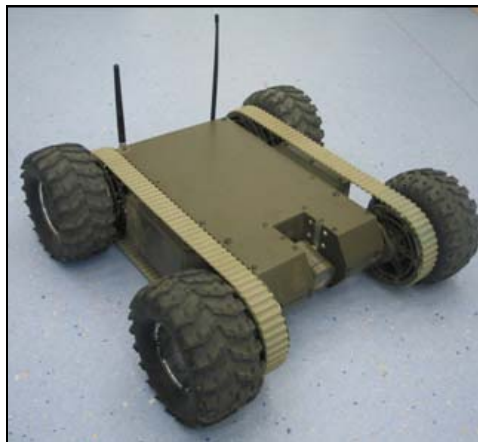
PIAP offers mobile robots designed for inspection, transportation and neutralisation of hazardous devices. Explosive ordnance disposal/improvised explosive device disposal (EOD/IEDD) robots—EXPERT, INSPECTOR, and SCOUT—have been designed in cooperation with end users and security specialists (see Figure III-12).<sup>115</sup> <sup>116</sup> In 2000, the Polish Police purchased the first robot of the INSPECTOR series.



(a) EXPERT



(b) INSPECTOR



(c) SCOUT

**Figure III-12. PIAP EOD/IEDD Robots**

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<sup>115</sup> Army Technology Web Page. PIAP - EOD/IEDD, search and HAZMAT handling robots. Available: <http://www.army-technology.com/contractors/mines/piap/> (Accessed February 2008).

<sup>116</sup> See also <http://www.antiterrorism.eu/> (Accessed February 2008).

## 10. Russia

Several Russian organizations have programs in robotics.<sup>117</sup> Major activities of note are

- Bauman Moscow State Technical University (BMSTU), Mechanical Engineering Department: automatic systems and robots; mobile robots and high-speed tread vehicles; underwater vehicles and robots
- Moscow State Institute of Radiotechnics, Electronics, and Automatics: autonomous control systems
- The Russian Academy of Sciences (RAS) Institute for Problems in Mechanics (Lab of Robotics and Mechatronics): wall-climbing robots

The State Research Centers are Centers of Excellence in applied technology, and three of these centers are noted for mechatronics and robotics:

- The State Scientific Center of Russia – The Central R&D Institute for Robotics and Technical Cybernetics in St Petersburg: This center was formed in 1968 and is now reportedly one of the largest Russian research centers. It focuses on robotics and cybernetics research and design for space, air, land, and sea applications. It has developed several mobile robots for security, EOD, nuclear operations, and remote analysis applications.<sup>118</sup> The Institute is also working with the St. Petersburg State Polytechnical University on UAV and robotic snakes.
- The Kurchatov Research Center: light, mobile, remotely controlled robotic systems designed for the disposal of explosion-hazardous objects
- The Central Scientific and Research Institute Elektropribor: Areas of major potential growth in robotics work include defense, security, medical and healthcare, industrial automation, and nuclear cleanup (with experience from Chernobyl).

BMSTU's Department of Tracked Vehicles and Mobile Robots was established in 1936. The university is credited with a significant role in several Soviet ground combat systems. At one point, the university hosted a Department of Special Robotics, which was touted as a leader in technology from the mid 1980s. Some systems listed on the university's Web site are explicitly designed for counter-terrorism or military EOD and for chemical and radiation monitoring and remediation. The current research organization

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<sup>117</sup> UK Department of Trade and Industry (DTI) Global Watch Mission. November 2006. *Mechatronics in Russia*.

<sup>118</sup> CRDI Web Site: <http://www.rtc.ru/index-en.shtml> (Accessed February 2008).

comprises seven Research Institutes, two of which are important to this discussion: (1) Informatics and Control Systems and (2) Robotics and Complex Automation. Activities include navigation systems and systems for movement control of vehicles. The systems appear to be straightforward in design, with wheeled or tracked propulsion, and simple vision systems and mechanical manipulators for direct human operation (see Figure III-13). References to autonomous robots are limited to systems for lunar and planetary exploration.<sup>119</sup>



**Figure III-13. Sample BMSTU Ground Robot**

Novaya Era (New Era) in St. Petersburg is described as designing a new generation of robots for the armed forces of Russia. The company, which specializes in control systems for ships, appears to be interested in the development of robots for marine EOD, rescue, and surveillance and inspection (the so-called “electronic eye” robots).<sup>120</sup> The company was formed in 1993, as a follow-on to a Soviet-era company, Era, that manufactured and repaired electrical equipment for the Baltic Fleet. Recent developments include humanoid robots, described in the press as the only humanoid-robot project in Russia. The most important challenges according to a company spokesman are enhancement of the walking algorithm, development of hand functions, and improvements in vision and machine intelligence.

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<sup>119</sup> Bauman Moscow State Technical University Web Site: <http://www.bmstu.ru/english/science.html> (Accessed February 2008).

<sup>120</sup> Central Research Institute Web Article. 23 September 2003. Russian shipbuilding. Available: <http://shipbuilding.ru/eng/news/2003/09/23/robots/> (Accessed February 2008).



Participants in an EU program for Multi-Agent Robot Systems for Industrial Applications in the Transport Domain included the Institute for Informatics and Automation of the RAS (Laboratory of Neural Computing and Intelligent Control), Belarusian State University (Cybernetics Department), the Ufa State Aviation Technical University (Technical Cybernetics Department).<sup>121</sup>

## 11. South Korea

South Korea's Agency for Defense Development (ADD) is reported to be developing a family of experimental autonomous vehicles (XAV) wheeled robotic military vehicles (see Figure III-14). The ADD is currently testing the models and expects to deploy them sometime in the 2013 to 2020 timeframe. The XAV are available in surveillance and combat versions.<sup>122</sup>



(a) Surveillance XAV



(b) Combat XAV

**Figure III-14. ADD Experimental Autonomous Vehicles**

The surveillance model weighs 1.2 tons and can reach a speed of approximately 19 mph using battery power. The combat model weighs 0.9 tons and can reach a speed of 28 mph using a gas engine. Both XAV are armed with a 5.56-mm machine gun. They are listed as having autonomous capabilities; however, the degree of autonomy/level of supervision required is not known. A paper published by ADD researchers indicates that

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<sup>121</sup> Community Research and Development Information Service (CORDIS). Available: [http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ\\_RCN=2007228&CFID=4841517&CFTOKEN=36607749&jsessionid=4230ac16261353526a72&q=D2C2B79CFE590FA7BED4FFA9A575226A&type=sim](http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ_RCN=2007228&CFID=4841517&CFTOKEN=36607749&jsessionid=4230ac16261353526a72&q=D2C2B79CFE590FA7BED4FFA9A575226A&type=sim) (Accessed January 2008).

<sup>122</sup> Engadget News Page. Korea unveils new military bots. Available: <http://www.engadget.com/2006/06/09/korea-unveils-new-military-bots/> (Accessed January 2008).

the XAV middleware implements the JAUS.<sup>123</sup> While these XAV were the only foreign examples that explicitly addressed the implementation of the JAUS, the XAV joint architecture is in the process of becoming a standard under the Society of Automotive Engineers (SAE) Generic Open Architecture (GOA) Framework and several software applications to support JAUS-compliant development are available as COTS.<sup>124</sup> This includes an open-source package (OpenJAUS) developed by University of Florida.

The South Korean MoD was reported in 2005 to be working with the Ministry of Information and Communication (MIC) to develop and deploy “a Horse-Like” combat-capable robot. The project will run through 2011 at a funding level of \$33.4B Won<sup>125</sup> (\$32.4M USD). Three different robot types with six to eight legs were proposed. The ADD and the Electronics and Telecommunications Research Institute (ETRI) were cited as the primary performing activities.<sup>126</sup>

Two unarmed ROBHAZ-DT3 tracked robots were authorized to be used by Korean forces in Iraq. This system was developed by the Korea Institute of Science and Technology (KIST) in cooperation with YUJIN Robotics and the Korea Advanced Institute of Science and Technology (KAIST). The system (see Figure III-15) supports sensors and a camera for reconnoitering dangerous environments and bomb disposal.<sup>127</sup>

## 12. Sweden

Totalförsvarets Forskningsinstitut (FOI) (the Swedish Defence Research Agency) supports R&D in military robots, particularly in the area of UAV. Bofors Defence AB produced a remotely controlled prototype: the 100,000-lb Mine Guzzler (see Figure III-16).<sup>128</sup>

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<sup>123</sup> Smithsonian Astrophysical Observatory/National Aeronautics and Space Administration (SAO/NASA) Astrophysics Data System (ADS) Physics Abstract Service. Component based open middleware architecture for autonomous navigation system. Available: <http://adsabs.harvard.edu/abs/2007SPIE.6561E..61A> (Accessed February 2008).

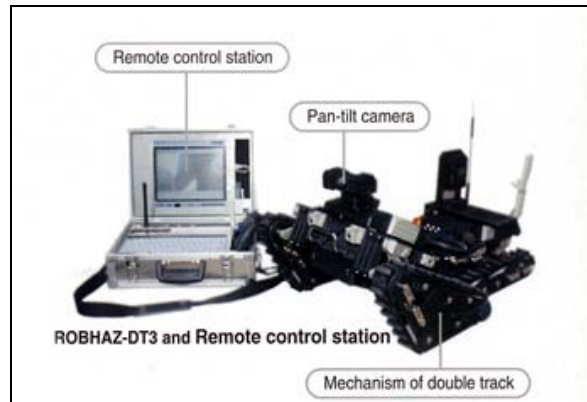
<sup>124</sup> JAUS uses the SAE GOA framework to classify the interfaces.

<sup>125</sup> The Won is the currency of South Korea.

<sup>126</sup> Korea.net News Page. September 2005. Gov't to develop horse-like combat robot. Available: [http://www.korea.net/news/News/LangView.asp?serial\\_no=20050921012&lang\\_no=4&part=104&Se archDay](http://www.korea.net/news/News/LangView.asp?serial_no=20050921012&lang_no=4&part=104&Se archDay) (Accessed January 2008).

<sup>127</sup> Robhaz Web Site. Robot for hazardous applications: ROBHAZ. Available: <http://www.robhaz.com/eng/default.asp> (Accessed January 2008).

<sup>128</sup> Bofors Defence Web Page. Mine guzzler. Available: <http://www.boforsdefence.com/eng/products/dem.htm> (Accessed January 2008).



**Figure III-15. The ROBHAZ System**



**Figure III-16. Bofors Defence "Mine Guzzler"**

The Centre for Autonomous Systems is an interdisciplinary activity at the Kungl Tekniska Högskolan (KTH) (Royal Institute of Technology). The Centre conducts research on most aspects of robotics—but with emphasis on real systems for real environments. The center comprises four groups: Control, Applied Mathematics, Mechatronics, and Computer Vision. Demonstration projects include service robotics, rough-terrain robots, and industrial applications of mobile robotics. Projects involve construction of a mobile platform that does autonomous mapping of an area using simultaneous localization and mapping (SLAM) and a user interface that allows an untrained soldier to operate the vehicle. The project uses an iRobot all-terrain robotic vehicle (ATRV) for navigation in urban settings.<sup>129</sup>

<sup>129</sup> KTH's Centre for Autonomous Systems Web Page. Research projects. Available: <http://www.nada.kth.se/~hic/projects.html> (Accessed January 2008).

KTH also conducts work in human-machine interfaces and UGV technology for urban environments. Work includes collaborative efforts with the Försvarets Materielverk (FMV) (the Swedish Defence Materiel Administration, a procurement agency for the Swedish armed forces) in an exploratory study of ground vehicles for military applications (e.g., scout functions, mobility support, and mine and UXO detection) and a project on the use of vision on air vehicles (for navigation and surveillance/reconnaissance functions). Work in UGV (see Figure III-17) for the urban environment is a particular area of interest. Luleå Tekniska Universitet (Luleå University of Technology) also has relevant research in mobile robotics, including the use of non-contact sensing and maps for navigation.<sup>130</sup>



**Figure III-17. Prototype Robotic Vehicle**

### **13. Switzerland**

The Autonomous Systems Lab (ASL) of the Institute of Robotics and Intelligent Systems (IRIS) at Eidgenössische Technische Hochschule (ETH) (Swiss Federal Institute of Technology) in Zurich was formed from the merger of the Center for Product Design at ETH Zurich and the former ASL at the EPFL. The new ASL has more than 40 members who conduct research focusing on intelligent systems and autonomous mobile robots. Research includes product design, manufacturing software, UAVs, mobility, obstacle avoidance, navigation, mapping, localization, planning, learning, and educational robotic platforms.<sup>131</sup>

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<sup>130</sup> Lulea University Robotics Department Web Site: <http://www.sm.luth.se/csee/ra/> (Accessed January 2008).

<sup>131</sup> Autonomous Systems Lab Web Site: <http://www.asl.ethz.ch/> (Accessed January 2008).

The IDIAP Research Institute (Institut Dalle Molle d'Intelligence Artificielle Perceptive: Dalle Molle Institute for Perceptual Artificial Intelligence) is an independent, non-profit research institute focused on multi-modal interactions and multi-media information management. It was established in 1991 and is affiliated with the EPFL and the Université de Genève (University of Geneva). One of the institute's main projects is involved with the development of mobile robotics controlled by the brain. Previously, in 2003, its researchers reported a novel accomplishment—the non-invasive brain-actuated control of a mobile robot. In 2007, it presented its brain-actuated wheelchair navigation at the Institute of Electrical and Electronics Engineers (IEEE) 10th International Conference on Rehabilitation Robotics.<sup>132, 133</sup>

#### 14. Singapore

Singapore Technologies Kinetics (ST Kinetics),<sup>134</sup> the land systems arm of the Singapore Technologies Group, has developed and markets the Spider Light Strike Vehicle (LSV) (see Figure III-18).<sup>135</sup> Described as “combat-proven,” the Spider is a four-wheeled, remotely controlled UGV that can operate at a range of 500 m. ST Kinetics states that Spider has some semi-autonomous capabilities to lessen the operational burden. Plans call for full autonomy in the future. Cornell University used the Spider as the basis for their entry into the 2005 Defense Advanced Research Project Agency (DARPA) Grand Challenge.<sup>136</sup>

The School of Mechanical and Aerospace Engineering (MAE) [formerly called the School of Mechanical and Production Engineering (MPE)] at the Nanyang Technological University (NTU) has ongoing efforts in locomotion, path planning and navigation, mobile communications, power and drive systems, sensor fusion, and distributed intelligence for mobile robots.

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<sup>132</sup> IDIAP Web Site. The IDIAP research institute history. Available: <http://www.idiap.ch/about.php> (Accessed January 2008).

<sup>133</sup> Non-invasive brain-actuated control of a mobile robot. In *Proceedings of the 18th International Joint Conference on Artificial Intelligence, August 2003*. Available: <http://www.idiap.ch/publications/millan-2003-ijcai.bib.abs.html> (Accessed January 2008).

<sup>134</sup> ST Kinetics is partially owned by the Singapore government.

<sup>135</sup> National Defense News page. Singapore company toys with concepts of the future. Available: <http://www.nationaldefensemagazine.org/issues/2004/Jul/Singapore.htm> (Accessed January 2008).

<sup>136</sup> Garcia, E. Technical review of team Cornell's Spider, DARPA Grand Challenge 2005. Available: <http://www.darpa.mil/grandchallenge05/TechPapers/TeamCornell.pdf> (Accessed January 2008).



**Figure III-18. Spider LSV**

Researchers from NTU's School of Electrical and Electronic Engineering are investigating the use of millimeter wave (MMW) radar for robot navigation. Specifically, they are interested in the use of MMW radar range measurements for SLAM, an advanced enabling technology for sensor-based autonomous navigation and control.<sup>137</sup>

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<sup>137</sup> Jose, E. and Adams, M. Millimetre wave RADAR spectra simulation and interpretation for outdoor SLAM. School of Electrical and Electronic Engineering, NTU. Available: [http://www.ntu.edu.sg/home/eadams/Papers\\_Pub/Ebi\\_Jose\\_ICRA\\_camera\\_ready\\_feb26.pdf](http://www.ntu.edu.sg/home/eadams/Papers_Pub/Ebi_Jose_ICRA_camera_ready_feb26.pdf) (Accessed January 2008).

## GLOSSARY

€ symbol for the euro

3-D three-dimensional

3G third-generation



AAI Applied AI Systems, Inc.

AB Aktiebolag (Swedish: Limited Company on shares)

ACFR Australian Centre for Field Robotics

ADD Agency for Defense Development

ADF Australian Defence Force

ADS Astrophysics Data System

AFV armored fighting vehicle(s)

AG Aktiengesellschaft (German: stock corporation)

AI artificial intelligence

AIBO Artificial Intelligence roBOt

AIST Advanced Industrial Science and Technology

AMOR2HUMAN autonomous mobile robotics applied to human augmentation

APC armored personnel carrier

ARC Australian Research Council

Artist advanced real-time integration system testbed

ASIMO Advanced Step in Innovative MObility

ASL Autonomous Systems Lab

ATRV all-terrain robotic vehicle

ATV all-terrain vehicle



BMSTU Bauman Moscow State Technical University

BMVg	Bundesministerium der Verteidigung (the German Federal Ministry of Defense)
BOA	Bulle Opérationnelle Aéroterrestre (French Air/Land Operational Bubble networked air-land warfare concept)
BRITE-EURAM	Basic Research in Industrial Technologies for Europe–Europe/America
BWB	Bundesamt für Wehrtechnik und Beschaffung (Federal Office for Defence Technology and Procurement)



C2	command and control
C4I	command, control, communications, computing and intelligence
CAS	Chinese Academy of Sciences
CBC	Canadian Broadcasting Corporation
CBRNE	chemical, biological, radiological, nuclear, and explosive
CCD	charge coupled device
CEA	Commissariat à l'Énergie Atomique (French Atomic Energy Commission)
CF	Canadian Forces
CIM	Centre for Intelligent Machines
CIO	Consorzio Iveco – Oto Melara
CISA	Centre for Intelligent Systems and their Applications
CLAWAR	Climbing and Walking Robots
CMOS	complementary metal oxide semiconductor
CNRS	Centre National de la Recherche Scientifique (National Scientific Research Centre)
COBRA	Common Object Request Broker Architecture
CoMRoS	Cooperative Mobile Robot Systems Stuttgart
CONOPS	Concept of Operations
CORDIS	Community Research and Development Information Service
COTS	commercial off the shelf
CRIIF	Centre de Robotique Intégrée d'Ile de France
CSIRO	Commonwealth Scientific and Industrial Research Organisation



**D**

d.o.o.	društvo s ograničenom odgovornošću (Croatia) družba z omejeno odgovornostjo (Slovenia)	Limited Liability Companies
DARPA	Defense Advanced Research Project Agency	
DDSC	Direction de la Défense et de la Sécurité Civiles (French Civil Protection Agency)	
DDSV	Đuro Đaković Specijalna vozila Inc. (Duro Dakovic Special Vehicles)	
DGA	Delegation Generale Pour L'Armement (General Delegation for Ordnance)	
DGPS	Differential Global Positioning System	
DIS	Dipartimento di Informatica e Sistemistica (Department of Computer and Systems Science)	
DND	Department of National Defence (Canada)	
DoD	Department of Defense	
DRDC	Defence R&D Canada	
DSTO	Defence Science and Technology Organisation	
DTED	digital terrain elevation data	
DTI	Department of Trade and Industry	

**E**

e.V.	Eingetragener Verein (German: Registered Association)	
EADS	European Aeronautic Defence and Space Company	
EDA	European Defense Agency	
ELROB	European Land-Robot Trial C-ELROB (civilian applications) M-ELROB (military applications)	
EMP	electromagnetic pulse	
EOD	explosive ordnance disposal	
EPFL	Ecole Polytechnique Fédérale de Lausanne (Swiss Federal Institute of Technology – Lausanne)	
ESI	Engineering Services, Inc.	
ESPELSA	Especialidades Eléctricas SA	

ESPRIT	European Strategic Program on Research in Information Technology (of the European Union)
ETH	Eidgenössische Technische Hochschule (Swiss Federal Institute of Technology)
ETRI	Electronics and Telecommunications Research Institute
EU	European Union
EURON	European Robotics Network
EV	Eingetragener Verein (German: Registered Association)
<b>F</b>	
FCS	Future Combat Systems
FGAN	Forschungsgesellschaft für Angewandte Naturwissenschaften eV (Research Establishment for Applied Science)
FLIR	forward-looking infrared
FMV	Försvarets Materielverk (FMV) (Swedish Defence Materiel Administration)
FOI	Totalförsvarets Forskningsinstitut (Swedish Defence Research Agency)
FP5	Fifth Framework Programme
FY	Fiscal Year
FZI	Forschungszentrum Informatik (Center of Research)
<b>G</b>	
GmbH	Gesellschaft mit Beschränkter Haftung (German: limited liability company; business entity)
GOA	Generic Open Architecture
GPR	ground-penetrating radar
GPS	Global Positioning System
GROWLER	Ground-based Weaponised Light Experimental Robot
GTKB	Global Technology Knowledge Base
GUARDED	Generic Urban Area Robotized Detection for CBRNE Devices
<b>H</b>	
HUDEM	Humanitarian Demining



IAI	Israel Aerospace Industries
IAIS	Institut Intelligente Analyse- und Informationssysteme (Institute for Intelligent Analysis and Information Systems)
IARP	International Advanced Robotics Programme
IDA	Institute for Defense Analyses
IDF	Israeli Defence Forces
IDIAP	Institut Dalle Molle d'Intelligence Artificielle Perceptive (Dalle Molle Institute for Perceptual Artificial Intelligence)
IDS	Interaktive Diagnose und Service Systeme (Interactive Diagnosis- and Service Systems)
IECAT	Innovative Educational Concepts for Autonomous and Teleoperated Systems
IED	improvised explosive device
IEDD	improvised explosive device disposal
IEEE	Institute of Electrical and Electronics Engineers
ILDS	Improved Landmine Detection System
IMI	Israeli Military Industries
IMK	Institute Medienkommunikation (Institute for Media Communication)
IMS	Intelligent Manufacturing System(s)
IMT	International Mobile Telecommunications
IPA	Institut Produktionstechnik und Automatisierung (Institute for Manufacturing Engineering and Automation)
IPI	Image Processing and Interpretation
IPK	Institut Produktionsanlagen und Konstruktionstechnik (Production Systems and Design Technology)
IPVS	Institut für Parallele und Verteilte Systeme (Institute of Parallel and Distributed Systems)
IR	infrared
IRCCyN	Institut de Recherche en Communication et Cybernétique de Nantes (Research Institute of Communication and Cybernetics of Nantes)
IRIS	Institute of Robotics and Intelligent Systems

ISL	Intelligent Systems Lab
ISR	intelligence, surveillance, or reconnaissance
ISRI	Intelligent Systems Research Institute
IST	Information Systems Technology
ITER	International Thermonuclear Experimental Reactor

## **J**

JAUS	Joint Architecture for Unmanned Systems
JCF	Joint Coordinating Forum
JGRE	Joint Ground Robotics Enterprise
JIP-FP	Joint Investment Program for Force Protection
JRP	Joint Robotics Program
JRPMP	Joint Robotics Program Master Plan

## **K**

KAIST	Korea Advanced Institute of Science and Technology
KIST	Korea Institute of Science and Technology
KTH	Kungl Tekniska Högskolan (Royal Institute of Technology)
KUL	Katholieke Universiteit Leuven (Catholic University of Leuven)

## **L**

LAAS	Laboratoire d'Analyse et d'Architecture des Systemes (Laboratory for Analysis and Architecture of Systems)
LADAR	laser radar
LIST	Laboratoire d'Intégration des Systèmes et des Technologies (Laboratory for Systems Integration and Technology)
LMS	Laboratoire de Mecanique Solides (Laboratory of Solids Mechanics)
LSV	Light Strike Vehicle
LW&M	Land Warfare and Missions

## **M**

M&S	modeling and simulation
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M2M	machine-to-machine
MAE	School of Mechanical and Aerospace Engineering
MCTL	Militarily Critical Technologies List
MDA	MacDonald, Dettwiler, and Associates
MEMS	microelectromechanical systems
MIC	Ministry of Information and Communication
MiniRoC	Mini-Robots de Choc
MiroSot	Micro Robot World Cup Soccer Tournament
MMW	millimeter wave
MoD	Ministry of Defense
MPE	School of Mechanical and Production Engineering
MRS	Mini Robot Specialise
MS	mass spectroscopy
MULE	Multi-function Utility/Logistics and Equipment
<b>N</b>	
NARVAL	Navigation of Autonomous Robots via Active Environmental Perception
NATO RTO	North Atlantic Treaty Organization Research and Technology Organization
NATO	North Atlantic Treaty Organization
NBC	nuclear, biological and chemical
NEC	Network-Enabled Capability
NTU	Nanyang Technological University
NUDT	National University of Defense Technology
<b>O</b>	
OEI	Orion Enterprises, Inc.
OSD	Office of the Secretary of Defense
ODUSD (A&T)	Office of the Under Secretary of Defense for Acquisition and Technology
OUSD(AT&L)	Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics)

## **P**

PIAP	Przemystowy Instytut Automatyki i Pomiarów (Industrial Research Institute for Automation and Measurements) (Poland)
PMAR	Laboratorio di Progettazione Meccanica Applicata alla Robotica Industriale ((Laboratory of Design and Measurement for Automation and Robotics)
POC	point of contact
PRC	People's Republic of China
PRIMUS	PRogram for Intelligent Mobile Unmanned Systems
PRM	Petit Robot Modulaire
PSA	Portfolio Systems Acquisition
PTR	proton transfer reaction
PUGV	Portable Unmanned Ground Vehicle
PV	Protection Vehicle

## **Q**

QRIO	Quest for Curiosity (robot)
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## **R**

R&D	research and development
R&E	Research and Engineering
RAS	Russian Academy of Sciences
RCSS	Robotic Combat Support System
RDV	Remote Detection Vehicle
REC	Robot Eclaireur Reconnaissance
RHex	hexapedal robot
RMA	Royal Military Academy
ROTIS	Remote Operated Tankers Inspection System
ROV	remotely operated vehicle(s)
RSTA	reconnaissance, surveillance, and target acquisition
RTG	Research Task Group

## **S**

S&T	science and technology
S.A.	Société Anonyme (French company designation)
S.p.A.	Società Per Azioni (Italian: shared company)
S.R.L.	Società a Responsabilità Limitata (Italian: limited company)
SA	Sociedad Anónima (Spanish company designation)
SAE	Society of Automotive Engineers
SAM-UGV	Semi-Autonomous Small Ground Vehicle System Demonstrator
SAO	Smithsonian Astrophysical Observatory
SAR	search and rescue
SIA	Shenyang Institute of Automation
SLAM	simultaneous localization and mapping
SME	subject matter expert
SpA	Società Per Azioni (Italian: shared company)
SPIIRAS	St. Petersburg Institute for Informatics and Automation of the RAS
SRL	Società a Responsabilità Limitata (Italian: limited company)
ST Kinetics	Singapore Technologies Kinetics
STANAG	Standardization Agreement
SYRANO	Système Robotisé d'Acquisition pour la Neutralisation d'Objectifs (Robotic system for acquisition and neutralisation of targets)

## **T**

tEODor	telerob Explosive Ordnance Disposal and observation robot
The ROC™	Robot Open Control™
TRDI	Technical Research and Development Institute
TTP	tactics, techniques, and procedures

## **U**

UAV	unmanned aerial vehicle(s)
UCL	Universite Catholique de Louvain University College London
UCS	Unmanned Control System

UGent	Universiteit Gent (Ghent University)
UGS	unmanned ground system(s)
UGV	unmanned ground vehicle(s)
ULB	Universite Libre de Bruxelles (Free University of Brussels)
ULg	Université de Liège (The University of Liège)
UNSW	University of New South Wales
USD	U.S. dollars
USV	unmanned security vehicle(s)
UTS	University of Technology Sydney
UUV	unmanned underwater vehicle(s)
UXO	unexploded ordnance



VCS	Vehicle Control Station
VIPeR	Versatile, Intelligent, Portable Robot
VIPLAB	Visual Information Processing Lab
VR	virtual reality



WFR	WeiFu Robot
WMD	weapons of mass destruction
WTC	Worldwide Technology Capability
WTW	World Technology Watch®



XAV	experimental autonomous vehicle(s)
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